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THE INSTITUTION OF PETROLEUM TECHNOLOGISTS

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Members whose subscription is not in arrear receive the Journal free of cost, and additional copies are charged at the rate of 7s. 6d. per part, unless otherwise stated. A member whose subscription is not paid by March 31st of the year for which it is due is considered to be in arrear.

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A medal and a prize of five guineas is awarded annually by the Council to that Student Member of the Institution who shall, in their opinion, have presented the best paper during the session.

Benevolent Fund. The Benevolent Fund is intended to aid necessitous persons who are or have been members of the Institution, and their dependent relatives.

The Fund is raised by voluntary annual subscriptions, donations, and bequests, and all contributions should be sent to the Secretary of the Institution at Aldine House, Bedford Street, London, W.C. 2. The Fund is administered by the Council through the Benevolent Fund Committee, and all applications in connection therewith must be made on a special form which can be obtained from the Secretary of the Institution.

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Advertisements. Advertisements are inserted in the Journal, and information as to terms, etc., can be obtained from Mr. Thomas Tofts, 301-302, Bank Chambers, 329, High Holborn, W.C. 1. (Telephone No. Hol. 4776.)

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It is suggested that members send information regarding their movements to the Secretary, for insertion under this heading.

Mr. R. L. C. BLEECK is in Austria.
Dr. T. SUTTON BOWMAN is in England.
Mr. H. C. CARTER has left Burma and is now in Lower Assam.
Mr. S. O. CONNOR is coming home from Peru.
Mr. C. A. DORANS is coming home from Venezuela.
Mr. W. N. FOSTER is home from Trinidad.
Mr. F. E. J. FOXALL-SMEDLEY has returned from Burma.
Mr. G. HUNTER is home from India.
Lieut-Colonel R. H. T. JOBSON is coming home from Persia.
Mr. A. LLOYD is home from Burma.
Mr. A. N. LUCIE-SMITH is coming home from Venezuela.
Mr. D. P. REES is home from Trinidad.
Mr. T. C. RICHARDS has returned from Persia.
Mr. C. ROSS is on his way home from Burma.
Mr. J. C. ROSS is home from Venezuela.
Mr. J. D. SHACKLETON has returned to Burma.
Mr. G. E. WHEELER has left for Persia.
Mr. Y. P. WILSON is home from Iraq.
Mr. L. J. WILMOTH is coming home from Burma.
Ing. C. ZUBER has left Albania and is now in Poland.

The Secretary would be glad to hear of the whereabouts of the following members: C. A. Bauduin, E. H. Crush, C. J. Fielder, L. B. Holloway, C. E. Jobling, H. Leslie Little, Nand Lal Pasi, E. C. Scott, W. E. Shepherd, C. M. Stoney, John C. Templeton, R. K. Van Sickle and F. E. G. Watson.

OBITUARY.

THOMAS T. GRAY.

We regret to announce the death of Mr. Thomas T. Gray, which occurred on April 27th, 1931, at his home in Elizabeth, New Jersey, U.S.A. after a short illness. He was a notable figure in the refining industry, particularly on account of his invention of the Gray refining process and the Gray tower. At the time of his death he was president of the Gray Processes Corporation.

DINNER CLUB.

The attention of members is drawn to the Dinner Club of the Institution. This Club holds informal dinners after each General Meeting of the Institution and members may invite guests. Those desiring to receive notice of these dinners are requested to inform the Secretary of the Institution.

THIRTEENTH ANNUAL DINNER.

The Thirteenth Annual Dinner of the Institution of Petroleum Technologists will be held at the Connaught Rooms, London, on October 9th, 1931.

SIR JOHN CASS TECHNICAL INSTITUTE.

The Report on the work of the Department of Petroleum Technology for the Session 1930-31, shows that there was a total of 217 class entries and 4,144 student hours worked. These figures show a considerable increase on 1929-1930, when the totals were 160 and 2,876 respectively.

Six courses were provided during the session: (*a*) Lectures on General Technology of Petroleum, (*b*) Lectures on Internal Combustion Engines and Lubrication, (*c*) Introduction to the Chemical and Physical Properties of Petroleum, (*d*) Properties, Applications, and Examination of Petroleum, (*e*) Applications of Engineering, (*f*) Construction of Works.

UNIVERSITY OF PITTSBURGH.

The Department of Oil and Gas Production of the University of Pittsburgh is offering advanced courses in Petroleum Engineering, Drilling Equipment, Methods of Production, Transportation and Storage of Oil and Gas, Field Production Problems, Natural Gas Industry, Petroleum Engineering Seminar, and Research in Petroleum Engineering. Courses leading to a degree in Petroleum Geology and Petroleum Refining are also offered. Full information can be obtained from the Registrar, University of Pittsburgh, Pittsburgh, Pennsylvania.

FARADAY CELEBRATIONS, 1931.

In 1831 Michael Faraday made the discovery on which the science of electrical engineering and the great electrical industry has been founded. In order to commemorate the centenary of this event, the Royal Institution, with the co-operation of the Institution of Electrical Engineers, have undertaken the arrangement of the celebrations. The British Association for the Advancement of Science has also arranged for its Centenary Meeting to be held in London, and the Federal Council for Chemistry is participating in the arrangement of the Faraday Exhibition.

The provisional programme is as follows: September 21st, Reception by the Royal Institution; Faraday Commemorative Meeting at the Queen's Hall. September 22nd, Summer Meeting of the Institution of Electrical Engineers begins with Joint Conference of the Institution and Allied Associations; visits and social functions; Conversazione of the Royal Institution; Conversazione of the Institution of Electrical Engineers and Faraday Exhibition at the Albert Hall. September 23rd, Opening of the Faraday Exhibition to the public for about ten days; Opening Meeting of the British Association at the Central Hall.

The Royal Institution has decided to publish Faraday's Diary in full, and at least two of the six or eight volumes will be ready by September.

BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE CENTENARY MEETING.

The Centenary Meeting of the British Association will be held in London, September 23rd to 30th, and the Presidential address by Lt.-Gen. The Rt. Hon. J. C. Smuts, P.C., C.H., F.R.S. will be delivered at the Central Hall at 9 p.m. on September 23rd. For the period of the meeting, evening lectures, receptions, exhibits and excursions have been arranged.

SOCIETY OF CHEMICAL INDUSTRY. JUBILEE CELEBRATIONS.

In order to celebrate its Jubilee, the Society of Chemical Industry has arranged a series of meetings, receptions, and visits to industrial works from July 13th to 19th. Participation is confined to Members of the Society, except in the case of specially invited guests.

A series of authoritative papers illustrating the importance of chemistry in many industries will be distributed by the press and semi-technical reviews, and the Jubilee number of the Society's Journal, which will be mainly historical, will be available to non-Members at 10s. 0d. per copy. Dr. Miall's "History of the British Chemical Industry," the first authentic record will be published at 10s. 6d.

Origin of the Salt Domes of the Gulf Coastal Plain of the United States.

E. De Golyer (Member).

The salt domes of the Gulf Coastal Plain of the United States are of intrusive origin.[1] The common occurrence of contorted and flow structure in the salt itself, the circular or quasi-circular plane section of each of the salt masses, and their common cone or truncated-cone form, as well as the uplifting and faulting of the sedimentary rocks abutting the salt masses, and the bringing to or near the surface of blocks of rocks much older than the rocks which should normally be found at such depth, seem to establish this point. In fact, structurally, the salt dome resembles nothing in the realm of geology quite so much as it does a volcanic neck or plug, the salt core of the dome apparently having fulfilled the same structural functions as the igneous rock of the plug.

Evidence as to the origin and age of the salt and the associated cap rock and conclusions as to the mechanics of the actual dome formation are not so definite.

The salt is apparently of sedimentary origin and of Lower Cretaceous or greater age. The evidence is indicative rather than conclusive. Potash salts have been found in the salt masses of the Markham and Bayou Bouillon domes, indicating precipitation from sea water in the normal cycle of salt pan deposition. Algal remains, similar to or identical with those found in the salt beds of of the Kansas Permian, were found in salt from the Markham dome. This suggests similarity of depositional conditions, though, because of the possible time range of the algæ, not necessarily identical age. The position of the salt itself, underlying and uplifting rocks down to lowest Upper Cretaceous age, fixes the age of the salt definitely as Lower Cretaceous or older. Further, present definition of the age of the salt is entirely speculative.

[1] There is a voluminous literature on the subject of origin of these American domes. It has been reviewed and summarised by the writer in the special publication of the American Association of Petroleum Geologists "Geology of Salt Dome Oil Fields, Chicago, 1926."

Beds of salt occur in the Lower Cretaceous, though such occurrences are not yet known to be common. A bed of salt 23 ft. thick was found from 3675 ft. to 3698 ft. in the Glen Rose formation, Rycade Oil Corporation's Chittim Well No. 2, Maverick County, Texas; salt is reported to occur in the Lower Cretaceous, near Ojinaga, Chihuahua, and anhydrite and red beds found in the Lower Cretaceous of north-eastern Texas and northern Louisiana suggest the possibility of salt beds.

There is no definite evidence of the occurrence of strata older than Cretaceous. Wells drilled in the faulted region near Luling and Georgetown go directly from the Cretaceous into schists, probably a part of the basement complex. Prof. Schuchert, the dean of American palæographers, considers that this condition continues throughout a great part of the coastal plain and sees no possibilities of the occurrence of marine salts older than Cretaceous in the salt dome area. Evidence certainly favours Lower Cretaceous as the age of the salt, but it is by no means definite enough to preclude the possibility of future discovery that the salt is of Permian age.

The argument as to the mechanics of dome formation, so far as the American domes are concerned, must be largely by inference and comparison with salt domes and salt structures in other parts of the world. We have no information regarding the basal parts of the domes. No well penetrating the main salt stock of a dome has yet bottomed the salt. It is as if we were above a sea of clouds and could see isolated blunt topped peaks of salt sticking up here and there. The author's own theory of the mechanics of origin is that an older series of sedimentary rocks, including all of the Cretaceous and older rocks, was folded by orogenetic movement into a series of sharp and probably faulted folds, similar to the salt ridges of the Magdeburg-Halberstadt basin of Germany; that flowage of the interbedded salt was started by the compression of the folding; that deposition of Tertiary and younger rocks over the entire area started after the folding and flowage had begun, and that both deposition and salt flowage have continued intermittently to the present time, the salt masses from the breached or faulted anticlines being forced into or through the younger rocks and assuming, as a matter of least skin friction, the cone or tube-like form which is so characteristic of the American domes. This salt flow, intermittent in character, and assisted by water and clay lubrication and tidal kneading, continued in each individual dome until a condition of equilibrium was established. Many of the domes have been quiescent for a long period; some of the domes are probably active to-day.

The author believes that the cap rock, consisting chiefly of anhydrite and gypsum and occasionally, in part of limestone, with various minor minerals, is essentially a residue accumulating from materials originally deposited with the salt, but, through almost constant solution of the salt core by circulating waters, left as a detrital deposit. This residue, which at times contains material plucked from lower beds and carried upward by the movement of the salt mass, has been subject to compaction and alteration in the normal growth of the dome. The origin of the great sulphur deposits found in the cap rock of some of the domes is obscure, but may have resulted from the reduction of the gypsums and anhydrites. The oil deposits, whether in the cap rock of the dome, in lateral sands flanking the salt masses, or in shallow sands over the dome, arched by the upward pressure of the salt, are of secondary origin and are controlled by the various forms of structural traps incidental to a normal salt dome.

Moot Points in Salt Dome Theory.

By Launcelot Owen, A.R.C.S., A.R.S.M., D.I.C., M.Inst.M.M., F.G.S. (Member).

A comprehensive but, of course, still incomplete list of the almost innumerable problems arising from the study of Salt Domes was published by Donald C. Barton in 1925 (*Bull. Amer. Assoc. Petr. Geol.*, vol. 9) in an illuminating article. The research accomplished during the intervening five years has produced unfortunately very few satisfactory solutions.

The writer of this note, while realising the grave responsibility of adding to the already voluminous literature dealing with the many moot points, trusts that discussion, rather than the paper itself, will bring to light facts of value. Considerations of space forbid the acknowledgment by reference to the many authors to whom he is indebted for much of his material, but his thanks to them are none the less sincere.

(*a*) *The areal distribution of Salt Domes.*—Even to the casual observer, it is a striking fact that the deeps in the region comprising the Caribbean Sea and the Gulf of Mexico trend, in general, E.N.E.–W.S.W., while the shoals and dry land are disposed either along this trend or at right angles to it.

A study of the areal geology of the regions lying south of the Caribbean shows that the major systems of late—and post-Miocene faulting also follow these E.N.E.–W.S.W. and N.N.W.–S.S.E. trends, largely ignoring the local and regional directions of the earlier folding movements.

Applying this fact to the Gulf Coast area, it is reasonable to assume that the post-Miocene faulting in East Texas and Louisiana has been controlled by the foundering of the Gulf of Mexico, just as the post-Miocene faulting in the coastal areas of Colombia and Venezuela have been controlled by the foundering of the Caribbean. Unfortunately, the geological evidence of this faulting, within the Gulf Coast area, is completely masked by Pliocene, Pleistocene and Recent sediments. The general disposition of the salt domes, however, follows the trend of the trough of the Gulf of Mexico or a direction at right angles to it (*e.g.*, interior domes of Louisiana) and this fact at once suggests the possibility that the points of extrusion of these domes have been defined—at least during the latter phases—by a system of cross-faulting which, itself, has been controlled by the subsidence of the floor of the Gulf of Mexico.

(*b*) *The Derivation of the "Cap Rock."*—The majority of the known salt domes are capped by a layer of varying thickness, consisting chiefly of calcite, gypsum and anhydrite, in descending order. In the case of certain domes, this cap has been examined in detail and the reader is referred, especially, to the careful work of Marcus I. Goldman (*Bull. Amer. Assoc. Petr. Geol.*, vol. 9) on the Sulphur Mine Dome, Louisiana.

The derivation of the "limestone," or more correctly the calcite, which is found most commonly in the uppermost portion of the anhydrite cap, has been the subject of considerable conjecture. While it appears to be generally accepted that the calcite occurs as a secondary mineral—and, in fact, its mode of occurrence and microscopic characteristics leave little room for doubt on this point—its source has been attributed variously either to infiltering meteoric waters or to the alteration of the anhydrite or gypsum to calcite by reaction with petroleum.

In the laboratory, where conditions of temperature and pressure are largely under the control of the chemist, we can achieve the change $CaSO_4 \rightarrow CaCO_3$ (though not quantitatively) in several ways. One of the simplest of the many possible chemical permutations and combinations may be written :—

$2\,CaSO_4 + C_2 = 2\,CaCO_3 + SO_2 + S - 50{,}380$ calories, and it may be noted that the reaction is endothermic. Some of the other possible reactions, using $CaSO_4$ and hydrocarbons, are exothermic, but they all agree in requiring conditions of high temperature in conjuction with comparatively low pressure. Few geologists will be prepared to admit the probability, or even the possibility of such an environment during any phase of the development of a salt dome, and it is, in fact, difficult to conceive a mass change of $CaSO_4$ to $CaCO_3$, within or around the anhydrite cap, without violating the laws of thermodynamics, particularly when we bear in mind that the heat of formation of $CaSO_4$ from its elements is 330,620 calories while that of $CaCO_3$ is only 270,800 calories.

We are forced, therefore, to trace our calcite to a source more in consonance with possible geological conditions.

Three sources suggest themselves :—

(i.) Calcite originally incorporated with the anhydrite,

(ii.) Limestone collected by the anhydrite cap during its upward movement,

(iii.) Calcite introduced by surface waters.

Any one, or all, of these sources may have contributed the calcite of the cap but, in most cases (i.) appears to suffice with (ii.) and (iii.) as possible subsidiaries.

Water acting on the material of the anhydrite cap would take into solution $CaSO_4$, $CaCO_3$, S and minor constituents. Subsequently, part of the $CaSO_4$ would be deposited as gypsum, then the $CaCO_3$ would be released as calcite and, finally, the sulphur would be thrown down. This order of precipitation corresponds with the results of Goldman's microscopic examination of the Sulphur Dome cores.

The mother liquor would still carry a large quantity of $CaSO_4$, which would thus be lost to the cap. Such secondary enrichment of the calcite and sulphur content of the upper part of the anhydrite cap by the differential removal of $CaSO_4$ may be assumed to have occurred at any period when the anhydrite shield, during its upward passage, encountered water-bearing strata.*

(*c*) *The Shape of the Salt Mass.*—In the great majority of published sections, the salt mass of the Gulf Coast domes is depicted either as a cylinder or as an acute truncated cone. While this configuration is founded, in many cases, on the depth of the salt as revealed by drilling, it should not be forgotten that very different interpretations of the form of the salt mass, particularly at depth, are possible on the available data. It is of interest, therefore, to enquire whether the tacit assumption of the cylindrical or conical shape, to the exclusion of others, is justified, either in general or in particular, as regards the American domes. We know that it is not so in the case of the intensely studied European salt masses.

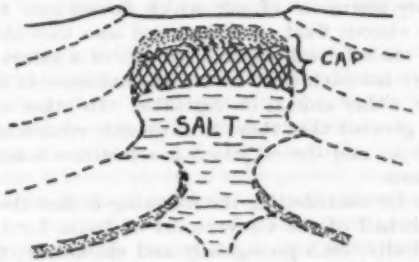
It is now recognized without question that salt under pressure behaves as a plastic mass. Salt, however, is not peculiar in this respect, for most materials known to us, even the "hardest," show indications of flowing when subjected to a pressure sufficiently great. On mechanical grounds, it is to be expected that any material, subject to a *differential pressure* in excess of its resistance to shearing, will flow. The resistance to shearing, in the case of salt, is comparatively low; hence the differential pressure required to cause salt to flow is relatively small in comparison with that required in the case of—let us say—limestone.

The physical properties of material subjected to a pressure in excess of its ultimate crushing strength are imperfectly understood, but, as both the effects of cohesion and surface tension will be nullified under such conditions, we may assume that the mass will flow, in whatever direction the pressure is released, much as would a highly compressed gas—without, of course, the property of indefinite expansion. The terms *solid*, *liquid* and *gas* lose their

* While the above was in the press a note by Dr. D. C. Barton (*Bull. Amer. Assoc. Petr. Geol.*, 1930, **14**, 1573), on Prof. L. S. Brown's work reached England. It is interesting to note that this work appears to confirm the opinions expressed above.

ordinary significance in such an environment. We may visualize, however, that the material will be extremely fluid and will pass readily along the lines of least resistance, provided always that the *differential pressure* (*i.e.*, the difference between the impelling force and the resistance to movement) is in excess of the shearing strength at the point of movement.

Under these circumstances, it is extremely improbable that a cylindrical or acute conical mass of the impelled material will be formed. The writer visualizes the resulting body as somewhat resembling an inverted cone in shape, but with a jagged surface, thus :—



Geophysical methods and interpretations, of greater refinement than we are able to employ at present, may throw light upon the true shape of the salt mass. If it resembles an inverted cone, as suggested above, the search for oil in the flank wells of the dome will not end with the striking of salt.

The writer makes no apology for attempting to indicate another potential source of enormous production of crude oil.

A Contribution to "Salt Dome" Geochemistry

By Murray Stuart, D.Sc., Ph.D. (Member).

In the preceding papers the mode of formation of salt domes occupied the centre of the picture and very little attention was directed towards the origin of the oil which is sometimes found in association with such domes. It can be taken for granted that salt domes are intrusions of salt which flowed into their present position in a viscous fluid condition, and also that the conditions under which the solid salt crystallized out of a saturated solution originally were not such as to favour the existence in the liquid of living matter, either animal or vegetable. In other words, it can be taken for granted that there is no genetic relationship between rock salt, *per se*, and the oil which is sometimes found associated with salt domes.

The excuse for contributing the following is that the author was deputed on behalf of the Government of India for two years to examine critically, both geologically and chemically, the vast salt formation in India which stretches from Jhelum in the Punjab to the North-West Frontier, a distance of over two hundred miles, and numbers amongst its natural outcrops some of the largest individual exposures of salt known in the world. In the course of that examination a fairly intimate knowledge of naturally occurring salt and its chemical and geological idiosyncrasies was acquired, and it seems possible that such knowledge gained from the study of a great salt deposit which has not been squeezed out of all recognition into a complex series of salt plugs, may be of assistance in clearing up what appear to be difficulties to those who have only come into contact with salt after all opportunity of studying it in its original position has been lost.

The first step towards the geological deposition of rock salt is generally the enclosing of a volume of sea water in an inland lake or sea. It is known that such waters quickly become stale, and Pirsson and Schuchert have shown that the lower layers are taken possession of by anærobic sulphate-reducing bacteria with the resulting liberation of sulphuretted hydrogen in the water. Before the concentration of the solution becomes too great, the upper sunlit and ærated layers of the water can be inhabitated by foraminifera and other forms of animal life, and the death and sinking of these minute creatures with their calcareous shells can, under certain circumstances and in the absence of bottom-living

predatory animal forms, give rise to the accumulation at the bottom of the inland lake or sea of material which in course of time becomes an oil-bearing dolomitic limestone. As the concentration of the saline solution approaches saturation, however, all animal and vegetable life in it would be inhibited, and the solid salts crystallizing out of a saturated solution would be free from the remains of animal or vegetable life such as might conceivably be the *ur*-material for oil deposits. It is just possible, therefore, that the conditions *preceding* the deposition and accumulation of rock salt might, in certain cases, have been such as to favour the accumulation of a dolomitic limestone containing oil. Other than this there can be no possible genetic relationship between rock salt deposits and oil.

When salt is deposited from evaporating sea water, the chemical and mineralogical nature of the material crystallizing out of solution does not remain uniform from beginning to end, the first material to crystallize out having different characteristics to that which crystallizes out at a later stage. This is to be expected, as the solubility of the different chemical salts present in sea water is not the same, and the chemical and mineralogical differences which can be observed in the succession of deposits from evaporating sea water can frequently be recognized in the great geological rock salt formations.

F. Bischof divides the Stassfurt salt deposits proper into four regions vertically, corresponding, he observes, to the natural order of origin from an evaporating solution[1]:—

(4) the Carnallite ($KCl.\ MgCl_2.\ 6\ H_2O$) zone;
(3) the Kieserite ($MgSO_4.\ H_2O$) zone;
(2) the Polyhalite ($2\ CaSO_4.\ MgSO_4.\ K_2SO_4.\ 2\ H_2O$) zone;
(1) the Anhydrite ($CaSO_4$) zone.

A similar division can be recognized in the salt deposits in the Salt Range and North-West Frontier Province of India. In India, what corresponds to Bischof's Anhydrite zone is grey salt containing sulphide of iron. It obviously crystallized out of a solution still containing sulphuretted hydrogen, liberated by the sulphate-reducing bacteria which had thrived in the preceding stage. When, and where, calcareous detrital material is washed or blown on to this grey salt at the present day, or the grey salt and calcareous rocks are brought into juxtaposition by faulting or any other means, gypsum starts forming as a "cap rock," or "parting," and the development of this secondary gypsum can be observed proceeding in every stage of its formation over an area of several

[1] *Ann. Chem. Phys.*, 1865, 5, 305. *Berg-und hüttenmannische Zeitung*, 1865, 24. See also H. Everding. *Deutschlands Kalibergbau*, 1907, p. 36.

square miles on the Bahadur Khel Salt Field. The chemistry is perfectly simple. Rain water, which contains dissolved oxygen and carbon dioxide, decomposes the sulphide of iron with the ultimate liberation of sulphuric acid, and this sulphuric acid, in addition to reacting with the salt to form sodium sulphate, also reacts with carbonate of lime with the resulting formation of selenite, which subsequently slowly becomes devitrified and consolidated into massive gypsum.[2] Having seen this taking place upon the Bahadur Khel Salt Field, it is obvious, when one looks for it, that a similar production of secondary gypsum has taken place and is still taking place *above* the salt throughout the Punjab Salt Range, where the salt is not grey, but red, and does not contain any recognizable quantities of sulphide of iron, but corresponds approximately to Bischof's Polyhalite, Kieserite, and Carnallite zones. This red salt contains kainite ($MgSO_4$. K Cl. 3 H_2O), kieserite, polyhalite, and other soluble sulphates, and when these come into contact with water carrying lime in solution, or conversely when water carrying these sulphates in solution comes into contact with limestone, calcium sulphate is formed as a natural result. There cannot be the slightest doubt that in ninety-nine cases out of a hundred the calcium sulphate of the "cap rock" of a salt dome, if any, and that bounding the intrusion, if any, is a secondary mineral and has been formed in one of the above two ways, *and that it is not contemporaneous in age with the salt with which it is associated.* In the evaporation of sea water, calcium sulphate comes out of solution before salt, and *original* calcium sulphate deposited from an evaporaring saline solution *underlies* salt, it does not *overlie* it. Calcium carbonate is one of the most widely disseminated of what may be termed the freely soluble minerals in the rocks of the earth's crust, and practically all subsurface meteoric waters contain it in solution. Also practically all naturally occurring rock salt contains a considerable quantity of soluble sulphate. If anybody can point out any natural factor which would prevent the two from reacting when they meet with the resulting formation of secondary calcium sulphate, the author would be very grateful to hear of it.

In the papers presented, there has been a certain amount of speculation about the genesis of anhydrite. Most of that speculation, however, has been based upon the assumption that the anhydrite is an original mineral and not a secondary one. From its position in relation to salt domes much, if not all, which is not actually included in the salt is secondary. Dr. Lees has pointed out that the change from gypsum to anhydrite plus water would

[2] Murray Stuart, *Rec. Geol. Surv. Ind.* 1919, **50**, part 1, 61-93.

cause an increase of volume of 13 per cent. From this he comments that apparently the effect of pressure would be to prevent the dehydration of gypsum. In the case of dry gypsum, and in the case of original calcium sulphate being deposited from a simple aqueous solution, this would appear to be true. Let us, for the moment, confine our attention to the effect of pressure, and consider the case, not of a simple solution of calcium sulphate, but of chemical reaction between calcium carbonate and soluble sulphate in a solution saturated as regards common salt and the various salts which are invariably associated with rock salt deposits, such as might be expected to occur at some depth below the surface. It is at once evident that if the calcium sulphate formed by the chemical reaction annexed water of crystallization to form gypsum, then an equivalent quantity of dissolved sodium chloride and its associated salts would, of necessity, be precipitated out of solution, and the resulting total volume of the material we are considering would be greater than would be the case if the calcium sulphate did not annex water of crystallization, but came out as anhydrite. Apparently, therefore, the effect of pressure in such a case would be to cause the formation of anhydrite and to prevent the formation of gypsum.

There is another important factor to be considered, namely, what may be termed the affinity for water possessed by the various chemical compounds. This can, perhaps, best be illustrated by referring to the stage in an evaporating saline solution when kieserite begins to be deposited. When that stage is reached the concentration of the magnesium compounds in solution is such that the magnesium sulphate comes out of solution in the form of kieserite ($MgSO_4 . H_2O$) because of the dehydrating effect of magnesium chloride, which prevents the formation of epsomite ($Mg.SO_4 . 7 H_2O$).[3] The same inherent property of soluble salts would be operative in the case of calcium sulphate being formed by chemical reaction in a saline solution. It is, in fact, an almost exactly parallel case. Dr. Lees has referred to J. H. Van't Hoff and F. Wiegert's classic experiments proving that gypsum is converted into anhydrite in sodium chloride solutions at 30° C., and that in sea water the transformation takes place at 25° C.[4] Meteoric waters which have dissolved rock salt below the earth's surface would approximate more to concentrated sea water than to a simple sodium chloride solution, and 25° C. is not by any means an unusual subterranean temperature.

[3] H. Precht and B. Wittjen. *Ber. Deutsch. Chem. Gesell.*, 1881, **14**, 2134. See also F. W. Clarke. *Data of Geochemistry*, 4th ed., 1920, p. 222.

[4] *Sitzungsb. K. Akad. Wiss., Berlin*, 1910, p. 1140.

It is obvious, therefore, that pressure and the presence in the reacting solution of salts dissolved from rock salt would tend to influence the production of anhydrite rather than of gypsum, and in the author's opinion no further explanation need be looked for to account for its observed occurrences.

The fact that salt domes are frequently capped by a thickness of calcium sulphate, consisting of a lower layer of anhydrite in contact with the dome, and an upper layer of gypsum, covered sometimes, in turn, by a layer of secondary calcite, becomes immediately understandable in view of the fact that meteoric water carrying calcium carbonate in solution is percolating downwards, while the soluble salts leached from the dome are being disseminated upwards in that water. Obviously there is a level below which the concentration of the dissolved salts is sufficient to cause the formation of anhydrite and to inhibit the formation of gypsum, and above which it is too weak to do so. The layer of calcite overlying the gypsum was obviously deposited from the downward percolating water above the level reached by the dissolved sulphates leached out of the salt dome.

The distribution of gypsum and anhydrite in Persia in the country occupied by Lower Fars rocks, mentioned by Dr. Lees, also becomes understandable, and in this particular instance it does not matter which form the calcium sulphate formerly affected, as the inference seems unavoidable that the present-day question of gypsum or anhydrite is largely a matter of present-day conditions.

There is another observed fact in relation to "cap rock" to be explained, namely, the occasional association of dolomite with the gypsum. In the above suggested reaction between soluble sulphate and calcium carbonate it is obvious that where the soluble sulphate consists entirely, or largely, of magnesium sulphate the reaction of this with calcium carbonate will not only result in the production of calcium sulphate but at the same time a corresponding amount of magnesium carbonate will be formed. Dr. Sterry Hunt found, as the result of experimental research, that magnesium carbonate, at the moment of its formation, is capable of combining with calcium carbonate to form dolomite.[5] It would follow, therefore, that where magnesium sulphate is abundant in the salt forming the upper portion of a salt dome, dolomite can be formed from the reaction of the same with calcium carbonate collaterally with calcium sulphate. Consideration of the concentrations of the two solutions, and their relative proportions, would indicate that the dolomite would tend to be formed at a higher level above the dome than the gypsum, although a certain amount of intermingling would be possible.

[5] *Silliman's Journ.*, 2nd Series, XXVIII., 184.

In the above hypothetical reaction if carbonates of barium and strontium are substituted for calcium carbonate then heavy spa and celestine would be formed—both of which are occasionally found in nature associated with dolomite and gypsum.

If the above represents the explanation of the origin of the "cap rock," which sometimes occurs over salt domes, the question naturally arises as to why some salt domes in the world have such a cap rock while others, for example the Rumanian domes, have not got anything of the sort. The answer to that would appear to be that the different zones of a typical salt deposit have not only different mineralogical composition (involving a different percentage of combined water of crystallisation), but, as might be expected, become "fluid" at different pressures.

The composition of the Stassfurt salt zones is shown in the following table :—

Composition of Carnallite Zone.

	Percentage of combined water in whole zone.
55% of carnallite (39% water of crystallisation)	21·0
25% of salt (no water of crystallisation)	—
16% of kieserite (13% water of crystallisation)	2·08
4% of various other salts	—
	Total approximating to 25% by weight of the whole zone.

Composition of Kieserite Zone.

	Percentage of combined water in whole zone.
65% of rock salt (no water of crystallisation)	—
17% of kieserite (13% water of crystallisation)	2·21
13% of carnallite (39% water of crystallisation)	5·0
3% of bischofite ($MgCl_2$ $6H_2O$—53% water of crystallisation)	1·59
2% of anhydrite (no water of crystallisation)	—
	Total approximating to 8·8% by weight of the whole zone.

Composition of Polyhalite Zone.

	Percentage of combined water in whole zone.
Salt, with 6 to 7% of polyhalite (nearly 6% water of crystallisation)	0·5 approx.

Composition of Anhydrite Zone.

	Percentage of combined water in whole zone.
Salt and anhydrite (no water of crystallisation)	—

When the Stassfurt salt deposits were being laid down, the evaporating solution from which they were being deposited received repeated accessions of sea water, resulting in successive layers of calcium sulphate being intercalated in the accumulating deposits, particularly in the anhydrite zone. This calcium sulphate almost certainly came out of solution as gypsum, but in sinking through the concentrated lower layers became converted into anhydrite.[6]

The anhydrite zone of Stassfurt, therefore, cannot be taken as typical of the lower-most zone of salt deposited from an evaporating enclosed volume of sea water which consists of practically pure sodium chloride. For the purposes of this present discussion, however, the author proposes to refer to the lower-most zone of a typical deposit as the "anhydrite zone," since this name has been established by Bischof.

The effect of pressure (and for the present purpose the cause of that pressure need not be defined) on a sequence of salt deposits, as described above, is that the carnallite zone becomes "fluid" before the kieserite zone, the kieserite zone before the polyhalite zone, and the polyhalite zone before the anhydrite zone. This is exemplified in India—an interesting piece of evidence which will be referred to below. The result is that when a normal stratified salt deposit is squeezed up a salt plug the material does not become thoroughly mixed into a magma of uniform composition, but the zones retain, more or less, their respective individualities. In other words, the material squeezed up the salt plug is first of all the material from the carnallite zone, followed by the material from the kieserite zone, followed in turn by the material from the polyhalite zone, followed finally by the material from the "anhydrite zone," which in the case of a typical salt deposit consists of practically pure sodium chloride. It becomes evident that salt domes and salt plugs may exhibit, at the present day, any stage of the above column, according to the amount of material squeezed up the plug, the amount of denudation suffered by it and the country rock generally, and the complete or incomplete nature of the stratified salt deposits from which the material was derived. It is this fact which has given rise to the idea, sometimes expressed, that a salt plug, in the course of its formation, purifies itself and sheds all its magnesium and potassium compounds. There is not a jot or tittle of evidence that any such thing takes place (other than the reactions discussed in this paper), nor is the assumption necessary to explain any observed occurrence.

The salt domes of Rumania consist of remarkably pure salt and this salt belongs to the "anhydrite zone" of a typical deposit.

[6] Cf. F. W. Clarke, *Data of Geochemistry*.

The natural consequence is that, since the salt contains practically no soluble sulphates, no cap rock has been able to form over it.

It would seem to follow, therefore, that where the salt exposed in a salt dome belongs to the "anhydrite zone" of the original deposit, no formation of gypsum and anhydrite cap rock can take place (unless, as is the case in India, the zone contains an appreciable amount of sulphide of iron), whereas where the salt belongs to the higher zones and contains soluble sulphates the formation of such cap rock can take place.

The instance in India of the different "flow points" exhibited by the different zones in the salt under pressure is interesting. In the Salt Range the salt is covered by approximately 1000 ft. of strata along the scarp of the range. There is no evidence that it has ever been covered by anything approaching 10,000 ft. of strata, and the probable figure would appear to approximate more closely to that suggested by Dr. Lees as being necessary to render naturally occurring salt fluid. The representatives of the carnallite and kieserite zones exhibit well-defined flow structure, in the representatives of the polyhalite zone the flow structure is present but less evident, and the representative of the "anhydrite zone" (which in Kohat represents a typical case in that it contains practically no anhydrite) has not become fluid but has been converted into a salt schist, showing that pressure which can induce fluidity in the carnallite, kieserite, and polyhalite zones is insufficient to induce the same effect in the "anhydrite zone." It may be that the amount of water of crystallisation in the various zones has something to do with this differential effect, as the facts quoted above show that the ease of solubility, the quantity of combined water of crystallisation, and the tendency to flow under pressure are each greater as one ascends the normal sequence of deposits from evaporating sea water.

Before closing this paper it is interesting to note the fact that in his voluminous "Lehrbuch der Salinenkunde," published in Berlin in 1846 (Vol. I.), Dr. C. I. B. Karsten makes allusion to the Red Indians of North America perceiving the association of gypsum with rock salt and thinking one a decomposed form of the other rock. A. B. Wynne, who did such excellent work on the salt deposits of India, also records the interesting fact that the Pathans of the Kohat district notice the recurrence of these two minerals together, and have been heard to call the salt of their country Speenki ka bhai, *i.e.*, brother of gypsum[7]—this in a country where the base of the salt deposits has never been seen, and where, therefore, the original gypsum deposited before the salt is nowhere exposed.

[7] *Memoir. Geol. Surv. Ind.*, Vol. XI., Part 2, 1876, p. 6.

Salt Occurrences in Egypt.

By Harold Dabell (Member).

In that portion of the littoral of the Egyptian Coast of the Gulf of Suez known as the oilfield region lying between lat. 28·5 and lat. 26·46 and long. 33·20 and long. 34 boring has proved the existence of a large area consisting of salt-gypsum and marls of Upper and Middle Miocene age.

This region is bounded on the west by igneous ranges and on the east by the deep navigable waters of the Gulf. At least half of this region consists of islands and the shallow, but in many places, navigable waters which surround them. The remainder is coastal plain with a maximum width of eight miles to the hills.

For the purpose of these remarks the whole may be treated as stratigraphically uninterrupted except by the presence of igneous bosses; *exposed*, as at the Zeitia and Esh-Mellaha granite ranges, *assumed*, as at the probable igneous core to the island of Jubal and the Dishet El Dabaa and Abu Somer folds field, and *proven* as in the Abu-Mingarh fold.

Within this area there have been numerous deep borings made on apparent surface anticlinal structures. The most northerly is at Ras Dhib and although the oilfield region embraces a good deal of territory South of the islands, the salt area as proved by borings is not known to go further south than Abu Shaar where the minor Esh-Mellaha igneous range terminates and gives place to a much larger plain extending to the Red Sea hills with a width of 20 miles.

Sixteen deep bores widely distributed over the salt area prove the existence of the deposit. Within the area, however, is one bore at Gemsah which did not encounter salt or gypsum and six on Jubal Island which, whilst encountering gyspum, did not meet salt.

The true thickness of the deposit has never been ascertained in so far as only one of the bores, *viz.*, at Ras Dhib, has completely penetrated the series. The bore passed through 2,600 feet of salt, gypsum, and marls, and entered a bed of marls of Middle Miocene age containing *globigerinae*, at which point it unfortunately was abandoned. All other bores entered the salt series and were ultimately abandoned for the diverse reasons of loss of diameter, exhaustion of funds, and outbreak of war.

There have been no traces of free liquid petroleum in the series, or in any case not sufficient to obtain a sample, but there have been two instances recorded of the possible presence of paraffin wax, and a boring made in 1899 at the head of Zeit Bay records oil infiltration from a point in the salt beds.

At Gemsah headland, which has a width of 1,000 yards, the Eastern side contains one bore which encountered only limestone, the centre of the headland being mainly gypsum, and the western side mainly salt. This is the only section within the salt area which has displayed lateral variation in the character of the rocks and in the case of the limestone bore there is ample room for doubt as to the reliability of the sampling.

No index bed of any value has been noted in the whole series, but certain bores have exhibited features which were carefully recorded with a view to using them should occasion offer. There were reddish sands in one bore at Ras Bahar, igneous grit in another at Mulhaimet Island, and igneous pebbles in another at Abu Shaar.

So far analysis shows the salt to be pure sodium chloride with a colour generally white, often grey, and occasionally pink.

Potash salts in small quantities occur in many of the bores.

The majority of the gypsum beds have limestone in them amounting from traces to thin beds, and occasionally the latter may carry a little gas and rarely globules of oil.

There is no known exposure of rock salt in Egypt nor is it mined in the country.

The first oil in commercial quantity was found at Gemsah in the Miocene limestone bore previously referred to in these notes. The result of this success was a persistent but unsuccessful boring effort by various companies extending up to fairly recent times to find the Miocene limestone in other areas—chiefly on the islands where surface configuration gave rise to hope that they would prove to be true anticlinal folds. None of the islands with the exception of Jubal Island have given any evidence of rocks older than the salt-gypsum series.

Dr. Hume is of opinion that it is possible that the Miocene limestone passes underneath the salt-gypsum series.

The borings, having proved the existence of the salt, have also proved that the depth at which salt is first encountered is deeper on the mainland than on the islands. The average depth on the mainland being 800 ft. with a minimum of 750 ft. and a maximum of 1000 ft. The average depth on the islands being 450 ft. with a minimum of 350 ft. and a maximum of 550 ft.

The difference is interesting and cannot be explained by additional surface deposits as the mainland bores do not exhibit any

excess of this nature. There is generally a less depth on the islands to the first layer of gypsum than there is on the mainland.

An east and west sectional view of the salt surface indicates a probability of a lenticular form to the deposit with the highest part at Mulhaimet Island.

Lees has aptly described some of the surface features in the Egyptian area under review as false domes, for such in fact too many of them have proved one after the other to be. This applies to borings made at Ras Bahar, Ranim Island, Mulhaimet Island, Gaysoom Island and Ashrafi and the Abu Shaar plain.

The maximum depth so far attained in the series has been 5193 ft. on Mulhaimet Island.

The maximum thickness of any single salt bed is 750 ft.

The only evidence of fossils in the gypsum is a *Corbula* bed at Gemsah in the gypsum cliffs, of which the casts are now entirely gypseous and assigned by Bullen Newton to the Plio-Miocene. Dr. Hume found a massed-cast bed at the summit of the main gypsum at Ras Benas—the casts being those of a small Venus and in his "Oilfields Region of Egypt" he instances the presence of selenite gypseous casts of an inflated bivalve (*Diplodonta*) at Hurghada.

When the salt area is not interrupted by the rising of older rocks there is no reliable evidence of the presence of petroleum. Where, however, there has been interruption, such as by the igneous ranges of Zeitia, Esh Mellaha, and the bosses of Gemsah and Jubal, there are unmistakable evidences of petroleum either in impregnated limestones or as a free liquid in small and unremunerative quantity.

Nothing in the nature of a capping rock to the series has been observed and no boring has gone into salt without having first traversed gypsum.

DISCUSSION.

Dr. E. R. Lilley said that there were two comparatively recent developments that he believed both Mr. Clapp and Mr. De Golyer would have included had they been able to present their papers in person.

Although it might appear to be only a minor point he wished to call attention first to the reaching at Esperon Pool in Liberty County, Texas, of a slightly lower horizon than had previously been attained. The formation reached was the Upper Saline Bayou series, a part of the Cook Mountain of the Claibourne group of the Eocene. The comparatively recent character of this—the

deepest formation definitely known to be present in the Gulf producing area—was a very positive indication of the difficulties faced by the student of the origin and mechanics of salt dome movement in this area. The character and thickness of the earlier Tertiary and Cretaceous beds known along the rim of the Gulf Coast Embayment led one to question whether the roots of the salt cores would ever be reached by the drill in the producing belt itself.

Dr. Lilley stated that the second point that he would like to mention was one of very considerable economic interest as well as scientific importance. He said that until recently it was very generally assumed that the Gulf Coast salt domes were upright in position and that though the angle of slope might vary substantially the sides of the salt masses always sloped away from the centres. The horizontal extent of the mass was generally assumed to increase steadily with depth. Wells that encountered salt were accordingly considered to be failures and were abandoned without further thought. However, during the past six months the drill had rewarded those who questioned this view. Wells at Barber's Hill and later at Lost Lake, Allen Dome, and Big Creek had found the typical oil laden coastal sediments after drilling through substantial thicknesses of salt. So far such wells have been located comparatively near the periphery of the known salt masses. It is, therefore, not yet possible to draw very definite conclusions concerning the form of the lower portions of the sale masses. The passage from salt into sediments may prove to be due to inclination of the salt mass as a whole. There seems, however, to be considerably more tendency to believe that at least some of the salt masses bulge at the top and become smaller in extent at lower levels, the bulged portion being referred to as "overhanging." If this proves to be the correct view, many of the salt domes whose lateral sands are known to be oil bearing will be thoroughly redrilled in efforts to secure production from points where these sands lie below the bulged or overhanging portions of the salt masses.

Mr. J. Romanes said the papers under discussion covered a very great range of territory; they stretched from the Gulf Coast in the West to Persia in the East, and he had the feeling that if that meeting were being held in 1941 instead of in 1931 those papers would probably cover a still greater range. In other words, just as at first oil was regarded as a rare and sporadic constituent of the earth's crust, but was now known to be anything but that, so with the spread of geological work the occurrence of salt domes appeared to him to be becoming more and more recognised as a

perfectly normal part of the geological history of many areas, and that being so, he thought that one must look for the explanation of salt domes in normal rather than abnormal geological processes.

Mr. Clapp had referred to the seventy-year-old controversy that had raged amongst geologists around the subject of salt domes, saying that "not until the past ten years have European views of the intrusion of an older salt mass through flowage seemed to be generally accepted." He thought, however, that one could probably go further, and say that had the evidence of Europe been available earlier, a good many of those theories would never have been put forward, since some of those earlier theories appeared to him as essentially calling on rather abnormal factors to explain the phenomenon. He did not think knowledge was in a sufficiently advanced state yet to enable one to say definitely that salt domes could only have one method of origin. There was in palæontology, or perhaps he should rather say zoology, what was known as heterogenetic homœomorphy, which was the development of two very similar types along quite different lines of ancestry, and it seemed to him quite a possibility that in the case of salt domes also there might be two quite different sets of factors at work in different areas giving rise finally to very similar salt domes.

In discussing such a subject one was a little apt, perhaps, to get together a whole series of apparently contradictory facts and theories, and he suggested that the logical way would seem to be to argue from the known to the unknown, and he did feel that in the German basin there were probably more factors definitely known, or at any rate factors for which there was very strong evidence, than in almost any other salt dome area. Therefore, he would briefly recapitulate the views that he had put forward with regard to certain important points with regard to the German area, in the hope that subsequent speakers might say how far they agreed with those theories with regard to Germany, and where those theories definitely would not fit other areas, what alternative theories must be put forward to suit the different data there.

Turning to the papers on salt domes, he thought that there were four main points under discussion, the first being the origin of the salt in salt domes, with which, of course, he included the age of the salt; secondly, the mechanics of salt dome formations, and closely bound up with that was the tectonical relationship between the salt and the surrounding rocks; thirdly, the very important economic question of the relationship between salt domes and oil; and fourthly and lastly, what was perhaps the most controversial point of all, the origin of the cap rock.

With regard to the German basin, he did not believe that anybody could seriously disagree with him when he said perfectly definitely that the salt in the German salt domes was the Zechstein salt, which was known, away from the domes, as a perfectly normal bedded saline deposit lying between the Lower Permian on the one hand and the Triassic on the other; there seemed to be no doubt whatever that all the salt domes of Germany had drawn their salt from that bed.

With regard to the second point, the mechanics of salt dome formation, perhaps the evidence was not quite so definite. At the same time, he felt very strongly that the evidence of Germany was that, while the distribution of the domes was probably due to tectonic lines, either faults or folds, the actual driving force that had given rise to the domes themselves was the weight of overburden, which rendered the salt plastic and therefore subject to flowage along the lines of least resistance.

With regard to the relationship of salt domes to oil, he thought the German evidence was that the relationship was the purely structural one of oil concentration round or over the dome, and that there was no genetic relationship between salt and oil. There was only one point in that connexion which occurred to him. He had sometimes wondered whether the very numerous sporadic occurrences of oil and gas within the salt in so many places could all be explained on the basis of migration. He thought that possibly Dr. Murray Stuart had thrown a certain amount of light on that, as there seemed to be the possibility of a certain small production of oil taking place along with salt-forming conditions.

As regards cap rock, the point involved seemed to be a very subtle combination of chemistry and geology, and he thought that discussion on it should, as far as possible, be confined to the question of origin in so far as it threw light on the origin of domes. There were so many subtle chemical questions wrapped up in it that there was always the fear of getting away from the main issue; it seemed to him that the balance of evidence, not only in Germany but elsewhere, was that the cap rock, the actual cap overlying the salt dome, was secondary, due either to chemical reactions or the solution of the salt leaving a residual deposit. He noticed that Mr. De Golyer took that view as generally applicable to cap rocks. He was sorry that no paper had been presented on Rumania, as a discussion on salt domes without a paper on Rumania was incomplete. There were many interesting problems there, such as the age of the salt, which had been the subject of much discussion, though in the latest publication it seemed to have settled down at the base of the miocene. There was also the question of the shape of those masses in Rumania. Were they the result of tangential

force as against overburden, giving rise to that form, or were they originally normal domes, deformed subsequently by tangential force.

With regard to one or two of the points that had struck him in the papers. One of the most difficult things, he found, to understand or formulate an explanation for was the fact, brought out by Dr. Lees and Mr. Harrison, that in the areas they dealt with the salt domes appeared to be independent of the tectonic structure. Apparently they penetrated the flanks of anticlines as readily as the crests. That seemed to be a very difficult thing to explain, because whether one took the view that the doming was due to tangential forces or to overburden, one would expect them to follow lines of least resistance which must be controlled by tectonics. This was a point needing further explanation.

In the same area Dr. Lees described the salt sheering perfectly sharply through a mass of limestone with practically no upturn of the limestone. Where had the limestone gone? Had it been absorbed to a certain extent by the salt, or had it been extruded at the surface rather like the "spine" of Mt. Pelée? It must have gone somewhere, and it was not represented by a steeply dipping flank.

Dr. Wade, he noticed, said that little attention seemed to have been paid to the fact that in the Gulf of Mexico, Persian Gulf and the Red Sea areas, salt domes seemed to be closely associated with tectonic depressions. He would like to know from Dr. Wade just what the inference was: did he link up the origin of the salt or the tectonics of the doming with such tectonic depressions. Personally he thought that widespread salt deposition belonged to continental rather than to marine conditions, as, for example, the great European Permian basin, which was essentially a continental rather than a marine phase.

Mr. E. H. Cunningham-Craig said that his first experience, or rather acquaintance, with salt domes was when he was advising a geological staff that was tackling salt domes for the first time, and receiving a beautiful map on six-inch scale, he saw clear evidence upon it that the domes shown on it had been produced by pressure from below. That had been rather strenuously contested later on. He had suggested at the time laccolitic action. Later again they were shown to be salt domes. At the present day there was very good evidence that there were three main sources of salt domes, a Pre-Cambrian one and a Permian one, and a third, which was not quite decided yet, but was probably Cretaceous; and there was also an incipient source which had not yet got to work, or not to any great extent, and that was Miocene. One was to be found in the Persian area, the second in Europe, and the third, the younger

one, in Texas, Mexico, Louisiana, and in New Mexico. There were a great many varying phenomena found about those domes according to how old they were, and where they were; but it seemed to him that it was impossible to make any distinction between them. There were certain fundamental facts. To begin with, there must be a mass of salt, he would say a bed of salt, ordinary bedded salt. It had been proved distinctly that those beds of salt existed in Europe. Then there must be a deep geosyncline, quite a thick one. Then all that was required was a little tangential pressure, not enough to make great anticlines, but enough to start the tendency to anticlinal folding in the lowest beds, and that started the action. Once that action was started, under what might almost be called the hydrostatic pressure of the surrounding rocks, it must go on continuously till equilibrium was attained. Naturally, owing to the friction, the oval or circular shape of the plug was determined, and as the plug went on breaking through everything, carrying everything before it, the salt became purer and purer. It was found in the oldest domes, those that had gone furthest, that there was the purest salt; it was found that potash salts, and so on, had been shed, that cap rock—and when he spoke of cap rock he meant really the cap rock over the original salt bed, not something that had formed secondarily at or near the surface; that was a different thing altogether—the cap rocks were shed bit by bit, probably nothing being carried at the end except possibly a certain amount of breccia made of fragments of almost everything that the salt had gone through. It seemed to him that these main fundamental points were applicable to all the salt domes that had ever been heard of. He admitted that he had often been puzzled as to the mechanics to some extent, and the action, and he had hoped to hear something new in the papers, but there was nothing new except very nice descriptions of some of the phenomena, and he had been driven back to the theory that he had stated very briefly, and which was practically the same as that of Mr. Romanes and Mr. De Golyer.

With regard to the starting up by a little tangential pressure, Dr. Lees pointed out that the domes in Persia were not orientated along the lines of the present, which was the latest, folding. That, however, had nothing to do with it, because the salt domes were orientated very clearly along lines which were oblique to the present and latest forces, but probably were the lines of earth movement at the time when those salt domes started. Having started them, the orientation could not be changed, no matter what folding had been done since. They might have halted at times, and gone on again as the pressure increased, but having once started they could not change their orientation; in fact, the domes came

out along lines which had been determined originally by tangential pressure. Evidence of that could be obtained in Texas, Louisiana, New Mexico, Transylvania—in fact, he thought everywhere where there was a fair collection of domes.

With regard to cap rocks over the salt, there was one point which Dr. Lees had made about whether anhydrite was ever deposited as anhydrite. In his own opinion, there was no doubt about that whatever. There were plenty of beds of it to be found in Egypt. It was generally slightly mixed with calcite, and some people had called it anhydro-gypsite.

It seemed to him to be quite clear that the old idea of the salt-bearing Miocene in Rumania had been put to rest for ever, and that Professor Voitesti, who had fought against that idea for so many years, was triumphant. In Rumania there was an enormous number of salt domes, and those domes were formed first, and then in certain zones subjected to tremendous pressure, sheered and split and drawn into long lenticles, but they were domes as formed first, and around those domes, while they were gentle features, the oil was concentrated purely through the structure.

There were a great many other minor points to deal with, but the whole thing seemed to him simple, granted that the salt could act as a plastic body, and that it actually sheered its way through and even got rid of intercalated beds. There is therefore really no essential difference between the salt domes that were known, whether they were young or old, whether they had gone far or whether they had only gone a short distance, or whether they were only beginning to move at the present time.

Mr. T. Dewhurst said that the first difficulty presented by the overburden hypothesis was the age of the salt. He granted that in North Germany the salt was of Permian age. In regard to the Gulf Coast, Mr. De Golyer's and Mr. Clapp's papers showed the uncertainty which existed as to the age of the salt in that region; it might be Cretaceous, Triassic or Permian. In South-west Arabia the salt might be of Triassic or even Cambrian age. In regard to Persia, Mr. Harrison stated that the salt was either early Cambrian or possibly pre-Cambrian. He referred to the abundance of igneous rocks and of various minerals in the salt plugs, and stated that some of these materials were probably of pre-Cambrian age. It followed that the salt was older than the igneous and other materials in the plugs, and therefore was probably pre-Cambrian. This conclusion recalled Professor Voitesti's view that the salt of salt plugs was deposited on the first permanent crust of the earth. The overburden hypothesis involved the assumption that salt was the oldest rock in the plugs, and therefore led to its source being pushed lower and lower in the geological succession. This seemed to him to be a

suspicious circumstance which tended to throw a little doubt on the over-burden hypothesis. In regard to the mechanism of salt plug formation, Mr. Harrison, in paragraph 55 of his paper, states that "Laboratory experiments on the plasticity of salt have yielded results that are quite incompatible with its observed behaviour in plugs and glaciers," and Dr. Lees in his paper states that "if the force necessary to make salt plastic is of the order of one-hundredth of that indicated by laboratory experiments, our conception of the problem is radically altered." In his (the speaker's) opinion, it was altered to the extent of abandoning certain facts and practically begging the whole question.

In regard to the incompatibility of laboratory results and field observations, the papers by Mr. Harrison and by Dr. Lees dealt with deep-seated plugs which had some 20,000 feet or more of over-burden. In North Germany there was much less over-burden, and therefore much greater incompatibility between the field evidence and laboratory results than was admitted in the case of Persia, and he thought that Mr. Romanes might explain that difficulty. In the Gulf Coast, similarly, the over-burden was much less than was the case in Persia, and he thought that Mr. Clapp in his reply might deal with the pressure difficulty in that region. Finally, reference to paragraphs 2 and 3 of Mr. Harrison's paper would show that in Persia he divided the salt domes into two main classes—those of deep-seated origin and those of shallow origin. He thought that Dr. Lees and Mr. Harrison, since they admitted the incompatibility of laboratory results with the evidence in deep-seated plugs, might deal also with the much greater incompatibility existing between laboratory results and the evidence in salt plugs of shallow origin. This incompatibility seemed to suggest that the over-burden hypothesis alone was inadequate as an explanation of the results, and that there was some other factor at work in the formation of salt domes than mere pressure due to over-burden.

His next point was that it was not enough to take a certain amount of evidence concerning salt plugs and then to bring forward a hypothesis, however attractive. That, he maintained, was practically all that the authors had done. In his view it was necessary to show not only that the hypothesis submitted explained the evidence, which in this case it admittedly did not, but also that the evidence was incompatible with alternative hypotheses. This had not been attempted except in regard to the hypothesis that the salt plugs were due entirely to lateral pressure. He would in particular like the authors to show that the evidence was incompatible with the hypothesis that the first stage in the formation of salt plugs was the fusion of sedimentary salt by heat due to vulcanicity, causing the salt to act like a lava. It seemed to be tacitly assumed by writers on the

subject of salt plugs that in some strange way vulcanicity managed to avoid areas in which salt had been deposited. In the Gulf Coast there was a salt dome region, and in Mexico there was another salt dome region. According to Mr. Clapp these two salt regions were genetically related, and were separated by an area which was penetrated by large and small masses of basic igneous rocks in the form of mountain masses, necks, dykes, faults and other structures.

He wished to ask Mr. Clapp if the vulcanicity was limited to the area in question and did not extend into one or both of the salt plug regions. In regard to South-West Arabia, Dr. Wade stated that there might be some geological significance in the fact that an area of volcanic rocks occurs in the adjacent portion of the Red Sea. Evidence which the speaker had seen suggested that the volcanic and the salt dome regions were adjacent to each other but did not over-lap; they seemed, as it were, to be complementary to each other. Further, the volcanic hypothesis would solve the difficulty presented by the presence of igneous and metamorphic rocks, and of characteristic minerals in the salt plugs of Persia. He had also read from time to time of the association of igneous rocks with salt plugs in North Africa and Spain, and understood that Mr. Wyllie had references to the relative literature. In view of the considerations he had put forward he suggested that the authors should endeavour to fit in the laboratory evidence with field results and to exclude the volcanic hypothesis, and any other alternative hypothesis that seemed worthy of consideration, before regarding the over-burden hypothesis as being in any way established.

Professor V. C. Illing said that he agreed with Mr. Romanes that, had the subject been tackled first in the European areas, a lot of the theories would never have been promulgated. He thought there was little doubt that a lot of the fog which surrounded the subject was due to the fact that the salt domes were mainly studied first in one of the most difficult areas, the plains of Louisiana and Texas.

There were so many minor points with regard to the whole question that he thought they had better keep in the main, in the short time at their disposal, to broad principles rather than to details. With regard to the origin of the salt, although not very familiar with the German area, he thought that the evidence was clear that the salt was of sedimentary origin, and that there, and also in the Persian area, the salt could be relegated to certain time limits. They were not in the same position in the Gulf States area. There, if sedimentary, the salt might be Lower Cretaceous, Triassic, Permian, or even deeper. The volcanic theory of the salt might not be ruled out in a minority of cases, but though there were certain attractive aspects of this theory it seemed improbable, if not impossible, in the majority of the cases.

The second important point was the question of the origin of the domes. Mr. Harrison had made some very illuminating remarks on the origin of the structures. His idea of the production of nuclei as the result of early pressure, and the modification of these by superincumbent pressure causing upward flowage along the lines of weakness, seemed to him to be in very close agreement with Mr. De Golyer's explanation of the origin of salt domes in the Gulf States.

Dr. Lees contributed useful data on the pressures at which salt became fluid. There was clear geological evidence that there had been salt flowage in the mechanics of salt dome formation. In certain dome structures the salt was clearly intrusive, just as a fluid igneous rock might be, and in fact there were closely analogous structures produced by salt plugs and igneous intrusions. Even if normally the load was insufficient, the presence of small quantities of water, surely, would induce flowage, and so it was difficult to put a minimum limit on the pressure necessary to produce these upthrusts.

With regard to the origin of the salt domes in Persia, if it was agreed that they were of pre-Cambrian or Cambrian age, it was quite possible that the nuclei that were produced were previous to the age of the recent folding. The original substructure was very difficult to decide, and it seemed to him quite possible that the present anomalous positions of the salt domes was due to these substructures and independent of the later movements that had taken place.

One of the most important subjects was the relationship of the oil deposits to the salt domes. Nearly all were agreed that the relations were structural and not genetic. That, surely, was one great step forward, whatever the subsidiary points of difference might be. The oil above the salt dome, the oil in the cap rock and the oil at the side of the salt dome had got there because the dome and its superstructure offered ideal facilities for oil concentration.

Dr. A. Wade said that more or less satisfactory answers had been given to the questions "What?" and "Where?" but he did not think that much advance had been made with "Why?"

Dr. Murray Stuart had apparently got nearer to the foundations of the problem than did most writers, and he (the speaker) was able to confirm many of his observations and conclusions from personal experience in the Red Sea and elsewhere.

The problem of origin interested him more than anything else in connection with salt domes, and he proposed to deal with it from the point of view of geological common sense. Starting at the surface, with "salt glaciers," nobody seemed to have noted "gypsum glaciers," and yet they existed in the northern Red Sea area, one being at the southern extremity of the Zeit Range. A

study of these occurrences had satisfied him as to underlying causes, and he had even tried to measure the rate of flow of the gypsum, which lies like a blanket over the crests of old jagged ridges of igneous rocks to heights of 1,000 feet or more above sea level. In deep gullies it is coarsely crystalline and often converted to anhydrite which may preserve the forms of Selenite. On the heights, and where flow has taken place, it is finely crystalline and breaks up into a fine powder. What is happening is simple and evident. Flow is due to solution or partial solution under the action of dew or rains, or the occasional humidity of southerly winds laden with moisture, some of which is deposited on the mountain tops. The solvent action may be assisted by the presence of salt films deposited on the gypsum from spume blown in from the sea. Recrystallisation follows, and thus constant alternations of partial solution and recrystallisation, with some measure of gravitational flow in between, are obtained. Heavy rains are rare in the ranges, but at such times the flow is noticeably quickened. This is in accordance with established experience, and is what takes place fundamentally in an ordinary glacier. While he had not examined "salt glacier" phenomena, he had no reason to suppose that any different explanation need be sought.

He thought that these observations might have something to do with salt domes themselves. When one looked at the diagrams of salt dome structures one was at first inclined to think, as one author had said, of the driving of putty nails through deal boards, but further consideration showed that this would not do. Considering all the evidence he thought it could be agreed that the actual forces resulting in the formation of salt plugs arose from the weight of superincumbent sediments. The plugs were found in the bottom of basins, or trough-like areas, and the motive power which had caused the salt movements had arisen from pressures exerted by the greater gravitational columns on the rims. Proceeding further, it could be conceived that movements originating in this fashion would cause rumpling and rippling of the sheets away from the margins, with consequential thickening of the salt in places. This local thickening might continue to increase, the beds being forced up into sharper ridges and, finally, there might be fracturing and penetration, not as of a board by a nail, but by bursting, as of solid matter by air, as in the case of a burst rubber balloon.

Here he found two difficulties. First he would expect to find the resulting extrusions to be linear in character, more like volcanic dykes, and folds like the ripples in cloth. There were salt intrusions of this character in Rumania and elsewhere, but he found it impossible to account for the great number of salt plugs which were all more or less circular in section, unless he assumed that points of

weakness, such as the intersections of sets of joints or fault planes, pre-existed in the overlying strata and that the swelling salt was able to make use of these points of local weakness.

His second difficulty was to explain why, once the beds had been fractured, the salt should pass through the fracture and migrate to the surface through, perhaps, thousands of feet of sediments. Limestones, sandstones, loose sands, or clays, no matter how plastic they were, were not found doing this. One other important component of the stratified rocks, however, does do it everywhere. He referred to water and said that he could get no further without water. Salt again differed from all the materials mentioned in that it is soluble in water, and this accounts for the difference in behaviour.

Salt dome basins very frequently lie in areas of low rainfall, but there is some rain in all cases, possibly more considerable on the rims than in the centres. It is hard to believe that water does not find its way into the saline strata at times, and if this is so it is not necessary to make abstruse experiments and calculations as to the fluidity of the salt. Even if only small quantities of water reach the beds periodically this would materially assist in the transfer of material towards the lower areas in the basins, help to swell local accumulations, carry the saline matter upwards under hydrostatic pressure along zones of weakness in overlying beds, to cause a gradual resorting of material, the differential segregation of potash, sodium, calcium and other salts, produce all the phenomena found in connection with cap rocks, and explain many other matters in salt dome problems. The moment water was brought into contact with a soluble substance like salt the problem ceased to be one of passive solid matter and became one of a potential active and mobile liquid. Everything in connection with it begins to move; no stability is possible. At one stage we are considering downward moving water, then water rising under compulsion by reason of hydrostatic pressure, and finally a complicated state of affairs when we have to consider both ascending water and water which has found its way in through the break at the surface and is descending in and around the plug. It was impossible to draw more than the barest outlines of the part which must be played by water, even in small quantities, at any given time but with unlimited space of times in which to operate. He was glad to find that Van Tuyl[1] confirmed his views to some extent by stating that "the lubricating effects of waters circulating about the borders of the salt cores may be more important than is generally supposed." He is dealing with a small part of the field of action.

[1] "Contribution to Salt Dome Problem," F. M. Van Tuyl, *Bull. Amer. Assoc. Petr. Geol.*, 1930, **14**, 1041–1047.

Many difficulties arose from the inability of the human mind to visualise long periods of time, such as say a million years, and to assess such a factor at anything like its proper value. The time factor is still unmanageable as a component in geological problems such as the one under discussion.

Other difficulties were due to the fact that the human mind tends to make very sharp classifications and distinctions, for example, liquid and solid. In nature there is no such sharp division, both are aspects of matter possessing the same qualities and attributes in different degree. He rather thought that the mechanical problem in connexion with salt dome formation disappears if we forget about solids for a time and consider it as a problem of two liquids of appreciably different densities, a thick layer of the heavier liquid overlying a thin layer of the lighter one. What will happen? The lighter liquid thus placed will, if given a chance, say by some disturbance or some lead through, always tend to "float" through the heavy upper member and to come to rest at the surface of it. This is every-day experience; there is no difficulty about it. Considered as a liquid the salt *should* "float" up through the denser overlying layers as soon as or wherever opportunity occurs. It follows from this that cases may occur in which salt plugs are connected with no present layer of salt in the underlying strata or the plugs themselves may taper off to nothing at depth. It also explains the mushroom formation referred to by Dr. Lilley. It is possible to conduct experiments on a small scale on these lines with much less trouble than the usual research work carried out with coloured clays, glass containers and some kind of arrangement for pressures, and the results are almost as interesting.

He did not know whether he could agree completely with Mr. Dewhurst, but at the same time he could not think that there was any fundamental difference between the mechanics of morphology of salt dome phenomena and those of igneous intrusions. Mr. Harrison's diagrams can be matched with granite bosses and plugs occurring on the western tablelands of Madagascar, while Dr. Lilley's overhanging salt plug paralleled exactly the figure of a granite plug shown in his paper on Madagascar.[2] In association with the igneous intrusives in Madagascar, cases also occur which compare with the bringing up of broken masses of the Hormuz rocks to the surface by the upthrust of salt. He was sure, therefore, that the study of igneous intrusions would throw much light on these salt intrusives, and possibly the converse is true.

[2] "Madagascar and its Oil Lands," A. Wade, *J. Inst. Petr. Techn.*, 1929, 15, 2–29.

Dr. Lees finds some difficulty with regard to beds of anhydrite in association with salt dome deposits, but was it possible that the following changes had occurred? He (the speaker) had noted the conversion of calcium carbonate in fossils into sulphate in the form of gypsum,[3] and this took place not only on low-lying tracts where the deposition of gypsum was evidently taking place to-day, but it was noted in a cliff section where saline waters could not affect the issue. In another locality he found gypsum converted into anhydrite as pseudomorphs after large spherulitis aggregates of selenite. This, again, was in a cliff section in a gulley in the Red Sea Hills. Was it possible that some of these beds of anhydrite were originally beds of limestone which had gradually undergone this series of changes. He was in agreement with Dr. Murray Stuart's observations on the surface formation of gypsum and the conversion of carbonates and related materials into sulphates, either as gypsum or anhydrite.

He would like to touch upon the comparison of the drusy oil-bearing limestone found overlying the granite on the old Jemsah field with beds of a similar character found in similar circumstances on Jubal Island; the presence of large quantities of perfect individual crystals of sulphur in these beds on Jubal; the question as to whether or not there is in each case a secondary dolomitic "cap rock," not overlying a salt plug but overlying a granite plug or buried pinnacle of granite which had given rise to similar conditions and somewhat similar deposits to those found in the case of salt domes and originating, as he supposed, from the movements of limited quantities of water. There was evidence to support such a view on Jubal.

He referred to Dr. Lees' statement that the intrusive nature of the Jebel Usdum salt was first recognised in 1922, and stated that this was known at least ten years before.

In an article on Palestine[4] he had referred briefly to Jebel Usdum, and had anticipated Dr. Lees' suggestion with regard to Sodom and Gomorrah.

In conclusion, he noted that while salt had been studied in almost every country nothing had been done with regard to the salt deposits in England, and suggested that a study of these might be to advantage.

Mr. B. K. N. Wyllie said he would confine his remarks to one feature of Mr. Harrison's paper, where he thought his explanation was not altogether satisfactory—*i.e.*, the frequent abundance

[3] "Eastern Desert of Egypt," A. Wade. *Quart. J. Geol. Soc.*, 1911, **67**, 238–262.

[4] "Oil Prospects in Palestine," A. Wade. *Oil News*, 1921, **9**, 594–597.

of basic igneous materials among the rock-fragments brought up by the salt. Mr. Harrison, in his opinion, did not know quite where to place these; but their abundance compelled him to suppose that their original position was just above the salt in the early Cambrian. He could see no reason why they should not represent much younger intrusions which had invaded the salt and solidified in it owing to the chilling effect of the relatively high thermal conductivity of rock salt. In support of this idea he offered the analogy of the Upper Trias of Spain. That formation appeared to be identical in facies with the one of Cambrian age that had caused all the trouble in South Persia. It also consisted largely of salty red marls and gypsum, and there was ground for believing that it originally contained massive salt beds—though these had been to a large extent leached away. Common accessory minerals were specular hematite and bipyramidal quartz-crystals. The formation everywhere showed intense contortion, and it had evidently behaved in many places as an eruptive mass.

FIG. 11.

POZA DE LA SAL, BURGOS PROVINCE, SPAIN: PEAK OF DOLERITE IN SALTY RED MARLS, WITH SALT-PANS.

The Trias of Spain contained a large number of small dykes and bosses of basic igneous rock, which he took to be intrusions that had lost their mobility by giving up their heat to the salt. He could illustrate this by a picture taken at Poza de la Sal, near Burgos (Fig. 11). The hill in the middle was a broken-down

spike of dolerite. The surrounding beds were salty, gypseous red marls, which appeared to have domed up and to some extent pierced the overlying Jurassic limestones, some indication of which could be seen in the rim of hills that formed the background. The salty nature of the marls was shown by the salt pans, which utilised brine that trickled from the margin of the igneous rock. The age of the dolerite intrusion he took to be young Tertiary, because a similar association of dolerite with Trias marls and gypsum had been erupted, in an adjoining region, through strata of Oligocene age.

If the blocks of diabase carried by the Persian salt plugs represented intrusions that had invaded the salt, it was obvious that one could attribute a considerable part of the mobility of the Persian salt to temperature—thus relieving to some extent the strain to which some of the theories appeared to subject the factors of pressure and time.

Mr. T. R. H. Garrett said that in most, if not in all, of the Rumanian salt massifs there was evidence of tangential pressure. Many, being mined for salt, can be entered and examined in detail. But it must be remembered that there is no evidence for the existence of many of the salt massifs marked on the maps. All of the largest oilfields of Rumania are situated on the edges of salt massifs, and perhaps the wish has been father to the thought as regards many of the salt massifs shown.

With regard to the age of the salt there he had not himself seen any rocks brought up by the salt which he could definitely identify, but both Prof. Voitesti and Messrs. Hancock and Walter of the Romama-Americana had told him that at one salt massif to the east of Pacureti (speaking from memory, Valea Dulce) they had definitely identified Jurassic and Triassic rocks brought up by the salt.

Dr. J. A. L. Henderson said that on the question of the origin of the salt of "domes" and "glaciers," the attractive theory which was suggested by Mr. Dewhurst was not new, of course, and its possibilities intrigue geologists; but he did not see any necessity for going as far as vulcanism for the explanation of the origin of such salt masses, seeing that there existed so many instances of large stratified salt deposits, ranging from some of the oldest Palaeozoics up to late Tertiaries, in different parts of the world.

With regard to the formation of "domes," and the degree of plasticity, or "fluidity" of rock salt, the divergence of the experimental results carried out so far did not seem to him to afford any secure basis upon which he found any opinions of value, and certainly further experiments must be conducted with regard

to the plasticity of many types of rock salt from the oldest known to the most recent, before any useful purpose could be served by applying experimental results to the formulation of theories.

In regard to the oil associated with salt domes, he wished to ask those who considered that oil and gas were only associated structurally with the salt domes how they accounted for the presence of oil globules imprisoned in rock salt, and the abundant evidence of methane under high pressure within numerous small cavities or interstices of certain salt masses.

He would, however, like to say that his own opinion agreed also with that of the investigators who do not consider that the large oil deposits associated with salt domes or intrusions, have any necessary genetic relationship with the salt. During the past two years, he had drilled through an almost horizontal, well-bedded rock salt deposit, completely free from oil or gas, and had found, within less than 100 feet from the base of the salt, oil and gas under high pressure in normally bedded sandstones of the underlying shale series.

Dr. E. Parsons recalled that Dr. Lees had stated that the salt of India was of two ages—namely, Cambrian and Eocene. It would be remembered that in the speaker's paper on the North-West Indian Oilfield[5] he had pointed out that on stratigraphical lines the gypsiferous marls and gypsum were of Eocene age. In 1929 Mr. Wadia and Col. Davies, while working in the very area which Dr. Murray Stuart had described, had discovered that the gypsum and gypsiferous marls at Bahadur Khel were intercalated with bands of limestone. These workers called attention[6] to the discovery of *alveolines* in the limestone beds intercalated with the gypsiferous deposits, and correlated one specimen with *Alveolina ovicula* previously found in the Laki Limestones. This was the age that he had ascribed to the gypsiferous marks on stratigraphical evidence. It would seem that the salt deposits in the North West Frontier could not be of Cambrian age. The reason for the supposed Cambrian age of the salt of North West India was due to the finding of Cambrian *trilobites* above the salt in the Salt Range. As he had pointed out, this relationship was due to over-thrusting. The finding of limestones of Eocene age (Lower Chharat age) in the beds above the salt at Bahadur Khel proved that these deposits were of Eocene and not Cambrian age.

One wondered if the association of the Cambrian fossils in Persia with the salt might not be as fortuitous as the association of the Indian salt with Cambrian fossils in the Salt Range. Dr. Lees emphasised that the salt plugs had risen through possibly 23,000 ft.

[5] *J. Inst. Petro. Techn.*, 1926, **12**, 439–505.
[6] *Trans. Min. Geol. Inst., India*, 1929; XXIV., 202–222.

of strata. He further pointed out in his paper that there was a marked disconformity between the Asmari limestone and the Lower Fars Series. He (the speaker) understood that that disconformity was not known until extensive drilling operations had been conducted. Might it not be that there were similar disconformities below the surface, and that the salt plugs in their travel from the lower regions had picked up Cambrian fossils, when passing through such over-thrust strata. He understood from Mr. Harrison's paper that certain of the salt domes in Persia were in definitely highly over-thrust strata, and it rather appeared from one of Mr. Harrison's remarks, where he spoke of "salt plucking," that he had something of that kind in his mind.

The second point was the question of the relation of salt domes to lines of tectonic weakness. As far as he could gather, the only region where the authors were definite that the salt domes were not related to lines of tectonic weakness were in Persia, and there, as we have learnt, there was evidence of dis-similarity between surface and underground structures. Messrs. Clapp and De Golyer appeared definite that the Texas and Louisiana salt domes were associated with a definite line of tectonic movement, which could be traced in the other formations of Texas; and in Germany the relations of the domes were definitely along the intersection of two lines of movement. It might be that the absence of the relation of the salt domes in Persia to tectonic lines was possibly due to the difference between the surface structure and the sub-structure.

The last point was in connexion with the plasticity of the salt. When one was familiar with the saliferous and gypsiferous strata in India one had no qualms in regarding them as plastic in view of the curious folds which the strata had there developed. The photographs of the salt glaciers recalled at once the phenomena of ice glaciers, and the principle of movement by regelation, which had been described more or less by Dr. Wade in connexion with the gypsiferous beds of Egypt. Might not this re-crystallization itself have supplied the penetrating force. In this connexion there was a recent paper by Dr. Bailley Willis, who had been examining the Rift Valleys of East Africa and had brought forward an ingenious theory that the re-arrangement of the crystals in the large granite batholiths, lying in and around these rift valleys, had provided the uplifting and over-thrusting forces, which have resulted in these unique topographical features. If one could get, by the re-arrangement of crystals in a granite mass, earth-movements of such size as to effect such enormous areas as there were in East Africa and produce these remarkable land forms, how much more might one not get salt domes produced by penetration due to re-arrangement of the salt crystals themselves. That there had been such

re-arrangement was likely, as everyone had remarked upon the purity of the salt in the salt domes, proving how in the re-crystallisation of the salt the impurities were thrown out. If the uprise of the salt were due to the weight of the over-burden, then the superincumbent pressure was transferred to a tangential one. The least line of resistance therefore would be the vertical direction, and therefore the crystal arrangement should be in that direction. The speaker wished to ask if any who had worked on salt domes had any evidence of the definite arrangement of the salt crystals.

Dr. W. A. Macfadyen said he had two points to raise, the first in connexion with anhydrite. In the eastern part of British Somaliland there was a deposit of Middle Eocene anhydrite averaging some 300 to 350 metres thick, which extended over a proved minimum area of 70,000 square kilometres. It was nearly all finely banded (he thought certainly not seasonally) and usually of a mottled green to brown colour, weathering whitish. It seemed clear that this must have been laid down as anhydrite, the colour and not infrequent oil smell being due to traces of shale and organic matter deposited simultaneously. There were relatively few thin partings of green shale and limestone, an interesting point being that the latter were often largely made up of a tiny *echinoid*, which had been identified as *Sismondia polymorpha*, Duncan and Sladen. He believed this indicated that the series was deposited in shallow or very shallow water, which, if this was so, would rule out Dr. Lees's suggested explanation in that case. Another point was the entire absence of any known salt deposit with that enormous layer of anhydrite. The occurrence seemed to his mind to point to some sort of chemical precipitation of the calcium sulphate as a fine mud, rather than crystallisation from a concentrated solution, where the normal product is gypsum.

As to the age of the salt in the Farsan region, he regarded this as analogous to the Gulf of Suez salt, and therefore of Miocene age; so far as he knew that was the only salt in the Gulf of Suez area, and it was definitely dated. The geology and results of drilling at Zifaf Island in the Farsans might be fairly closely paralleled by many slight salt-containing anticlines in the Gulf of Suez. He found that, in his Farsan paper, he omitted to mention the presence of a little anhydrite a few metres above the salt in the Zizaf boring. The salt at Gizan appeared to be clearly intrusive to some extent. It was associated with sometimes highly contorted gypsum or anhydrite, and some green to reddish shales, which, though searched with some care and washed for a microfauna, yielded nothing organic. Fragments of the highly fossiliferous Erythræan Series of that area (of Pleistocene or late Pliocene age) were found *in situ* lying on top of the disturbed Gizan hills.

The Gizan Coast section showed a few metres south of the contorted beds a small fault; south of that again the beds had locally a very low dip, and the apparently conformable succession showed 1m. rubbly sandy hill-wash, 3m. brown muddy sands, and traces of shale, 3m. light yellow calcareous sands passing to sandy limestone, with the echinoid *Laganum depressum* and other common fossils of the Erythræan Series, 0·5m. red brown rubbly shale, 4m. banded gypsum or anhydrite.

That section seemed to him to be evidence of the probable late Tertiary age of the anhydrite, and might correlate the series with that of the gypsum (partly contorted), clays, sands, etc., found by Mr. Wyllie and Dr. Lees at Jebel Titaweb and Mugusim Island, 170 and 130 km. respectively north of Port Sudan. (See L. R. Cox, *Proc. Malac. Soc.*, 1929, p. 174.)

The Gizan anhydrite and shales, though they might be later in age, are lithologically close to the Miocene of the Gulf of Suez; they are entirely unlike the dark-coloured (?) Triassic shales without more than a trace of gypsum which he had seen in Somaliland. The pebbly sandstone at Gizan, though it has an order appearance, might possibly be associated in the same Tertiary series, but of this there is no definite evidence.

The Triassic Adigrat series described by Blanford from Abyssinia consisted mainly of massive sandstones, with some blue to lilac shales near the base. In Somaliland the series was similar; the sandstones contained rare silicified wood and doubtful plant remains, and were sometimes pebbly at the base. The series seemed to be of a terrestrial facies, as also in Abyssinia, and to resemble the Nubian sandstone. He had found no mention of a lagoonal facies north of Lugh in Italian Somaliland, 1400 kilometres due south of the Farsans, where gypsum appears in it in quantity. Unless Dr. Lees had further information on the point, therefore, he found it difficult to accept the Trias as a probable source of the salt.

Regarding Dr. Wade's paper, he had made very careful inquiries and search in the Farsans in 1926–1927, and failed to find any evidence of actual boring operations having been carried out by the Germans. The alleged presence of a salt mountain in the islands was, he thought, no doubt incorrect. He had walked over the greater part of them and visited any hills he could see, but neither found nor heard of any salt. One could assume that it would certainly be known to the native inhabitants if it existed. Guma was the name given to him by natives of a salt working said to lie about half a day's journey (possibly about 20 km.) inland from Loheiya.

The President said that it only remained for him, on behalf of the members, to offer a hearty vote of thanks to the authors of the papers, to those who had presented the summaries in the absence of the authors, and to those who had brought forward such excellent discussion.

The discussion was continued at an informal meeting at Aldine House, Bedford Street, London, W.C. 2, on Tuesday, February 24th, 1931, and the following conclusions arrived at:—

It was agreed that all the evidence so far available is in favour of the salt of salt domes having been derived from normal sedimentary saline deposits. These may be of any age.

It was agreed that the older theories of brine springs, force of crystallisation, change of volume due to hydration of anhydride and other similar ideas can now, in the light of present-day knowledge be definitely discarded, and that the prime factor in salt dome formation was the flow of salt due to pressure, aided possibly by inter-crystalline solution and re-deposition.

No evidence was brought forward to account for the flow of salt underground other than by earth pressure—*i.e.*, there was no definite evidence to suggest flow due to high temperature caused either by depth or contact with igneous magma.

The general impression was that both weight of overburden and tangential pressure played a part in salt dome formation. In the great majority of cases it would appear that while the orientation and initiation of the domes are due to tangential pressure, the driving force which uplifted them is mainly due to the weight of overburden. In certain rare cases—*e.g.*, Rumania—the weight of overburden seems to have played a very subsidiary part, these salt masses being in the main the extruded cores of normal orogenic folds.

On the subject of the origin of the cap rock no agreed conclusions were arrived at, as it was realised that further evidence and consideration were required.

There was a general consensus of opinion that, with regard to oil in commercial quantities, the salt domes merely played the part of giving suitable structures, either flank or cap, for the concentration of the oil formed in younger beds. It follows from this that if these younger beds are not oil-bearing it is possible for salt dome phenomena to exist with no chance whatever of commercial bodies of oil being found in association therewith.

It was agreed that there seemed to be a certain amount of evidence to show that the sporadic occurrences of small quantities of oil and gas within the dome might be indigenous. A useful line of research would be a careful chemical comparison between the oil within the dome with that occurring in commercial quantities around or on top of the dome.

The following written replies to the discussion were subsequently received :—

From **Dr. Murray Stuart :** With reference to Mr. Cunningham Craig's statement that " It is found in the oldest domes, those that have gone furthest, that there is the purest salt ; it is found that potash salts, and so on, have been shed." I should like to emphasize the point that there is no evidence that any such shedding of potash and magnesia, as suggested by Mr. Cunningham Craig, occurs, nor is any such assumption necessary to explain any observed fact as regards salt domes. I have gone into this question fully in my paper, and as evidence that such a thing is contrary to fact I would point to the existence of the great potash industry of Germany.

With reference to the statements of Dr. Lees and Dr. Ernest Parsons that part or all of the salt deposits of North-West India are of Eocene age, I would refer to Dr. Cyril Fox's paper,[1] which remains the latest official pronouncement on the subject, and which confirms the views as to age put forward by myself in Volume L. of the same publication. In view of the fact that the gypsum of the Bahadur Khel Salt Field is a secondary mineral, and is formed largely from calcium carbonate derived from the Nummulitic limestone, it is obvious that its age is post-Eocene. I actually showed on the screen a photograph of a boulder of Nummulitic limestone coated with a crust of gypsum, which can only have one interpretation as to the age of the gypsum. The age of formation of the secondary gypsum, however, has nothing whatsoever to do with the geological age of the salt, just as the age of the laterite in Western India has nothing whatsoever to do with the geological age of the basalt from which it is derived.

The salt of the Bahadur Khel Salt Field is a schist—a fact which cannot be too strongly stressed—and no one who has seen it can possibly hold the view that it is an undisturbed stratified deposit in its normal position in the geological scale. The fact that the gypsum of North-West India overlies in turn the " Anhydrite " zone, the Polyhalite zone, and the Kieserite and Carnallite zones of the salt, proves one thing—that there is a stratigraphical gap between the salt and the gypsum. Not only is there this discordance between the gypsum and the underlying salt, but there is also a structural

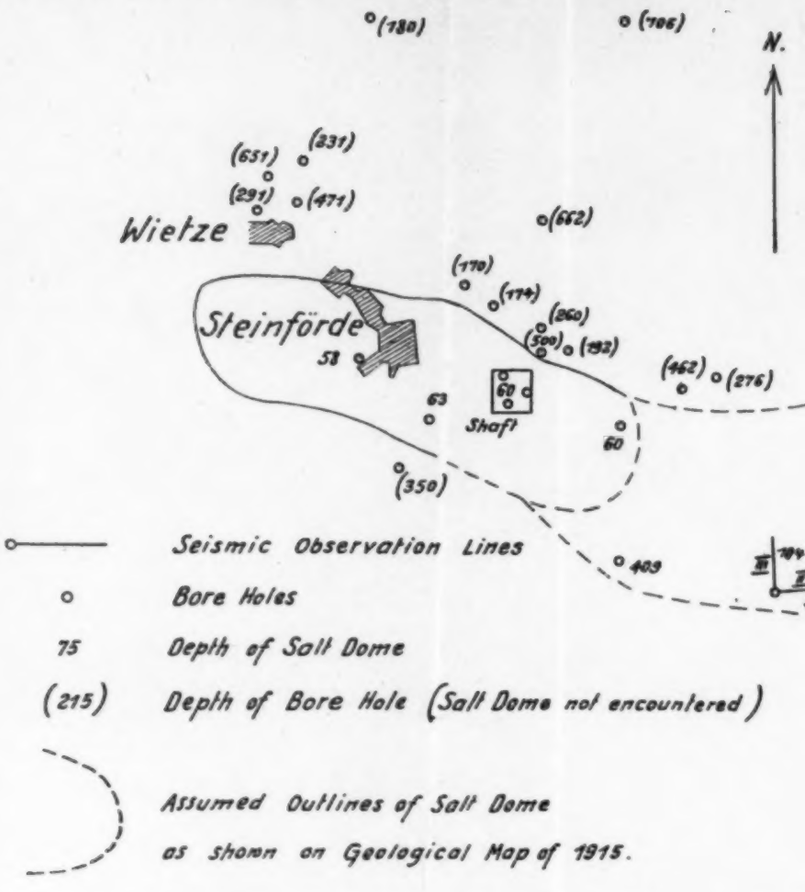
[1] *Rec. Geol. Surv. India*, 1928, **61**, Pt. 2, 147–179.

discordance between it and the overlying strata, the gypsum being overlain by Cambrian beds, Eocene beds and Miocene beds within a comparatively short distance. There cannot be the slightest doubt that the gypsum is a secondary mineral formed along the plane of a great overthrust fault and its associated riders wherever calcareous rocks have been brought into contact with the salt (an overthrust fault formed, probably, in the third main phase of the great Himalayan movement), and that the age of the gypsum is anything from the date of that fault to the present day—the formation of it is still going on at the present day. The age of the salt, on the other hand, is astride the pre-Cambrian and early Cambrian periods, represented in India by the desert Vindhyan sandstones and possibly the Delhi quartzites. The age of the Persian Hormuz salt, deduced by the geologists of the Anglo-Persian Oil Company, Ltd., fits in exactly with this great desert and salt lake period.

Had A. B. Wynne been aware, in the early seventies, of the order of sequence of natural salt deposits as established by Bischof, and had he realised that the gypsum is a secondary mineral, he would never have suggested that the Kohat salt was other than part and parcel of the salt formation seen in the Punjab—a suggestion which he based on the different chemical characteristics of the two salt exposures, but which, from his writing, he was not at all easy in mind about.

The question of age is one of distinct importance because of the fear that if there is any suggestion of the possibility of the Indian salt being of Eocene age, small operators in India may be tempted to drill through the salt in the search for oil. For this reason it cannot be emphasized too strongly that the evidence is practically complete that the salt of Kohat and the Punjab belongs to the same great salt formation and that it is of pre-Cambrian and early Cambrian age, and that the agreed opinion of this Institution is that there is no genetic relationship between rock salt and commercial oil deposits.

From **Mr. E. DeGolyer**: There seems to be some confusion with regard to the salt domes of the Texas-Louisiana coastal plain and those of the Isthmus of Tehuantepec, Mexico. Neglecting the rather doubtful Chapeño dome, the southernmost of the domes of the Texas-Louisiana group are Piedras Pintas, Palangana and Falfurias. Across the Gulf of Mexico, some seven hundred miles to the south, lie Ixhuatlan-Palmitota and Tonalapa, the northernmost of the Mexican salt structures. Each of these salt dome areas has its distinct and different geologic history. Even the salt masses are of different type, those of the Texas-Louisiana region being of the salt dome or plug type, and those of the Tehuantepec region being, for the most part, salt-core anticlines more of the German



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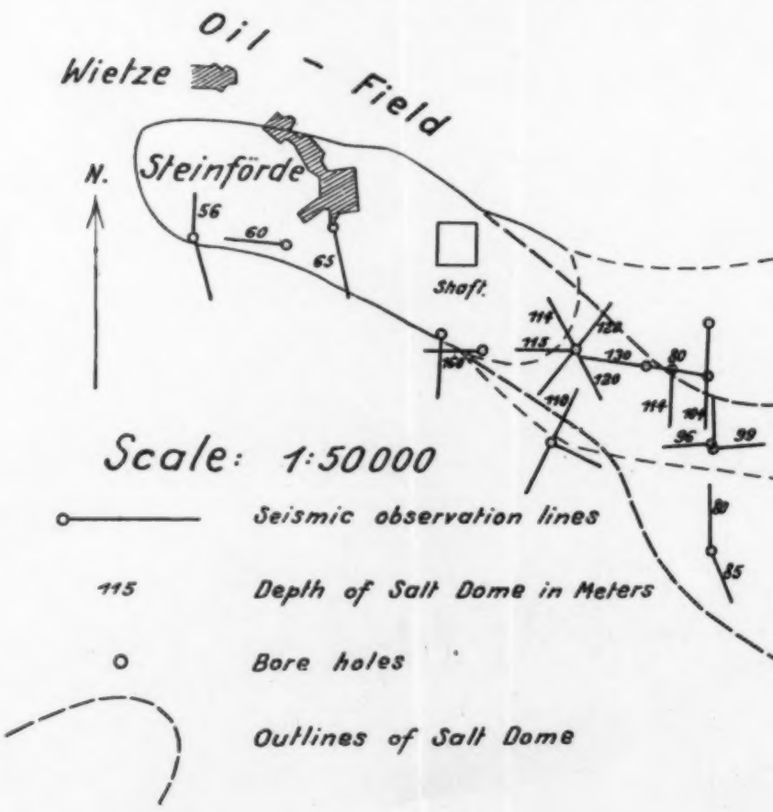

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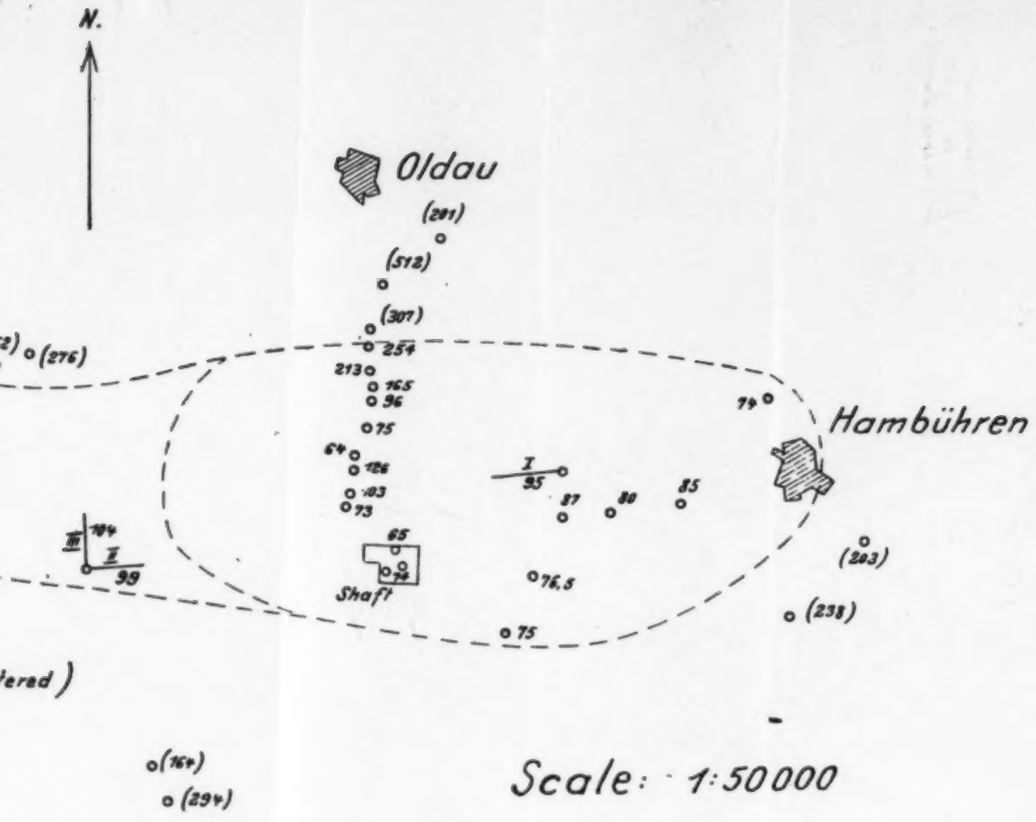

FIG. 1.

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teinförde and Hambühren according to Geological Map of 1915.

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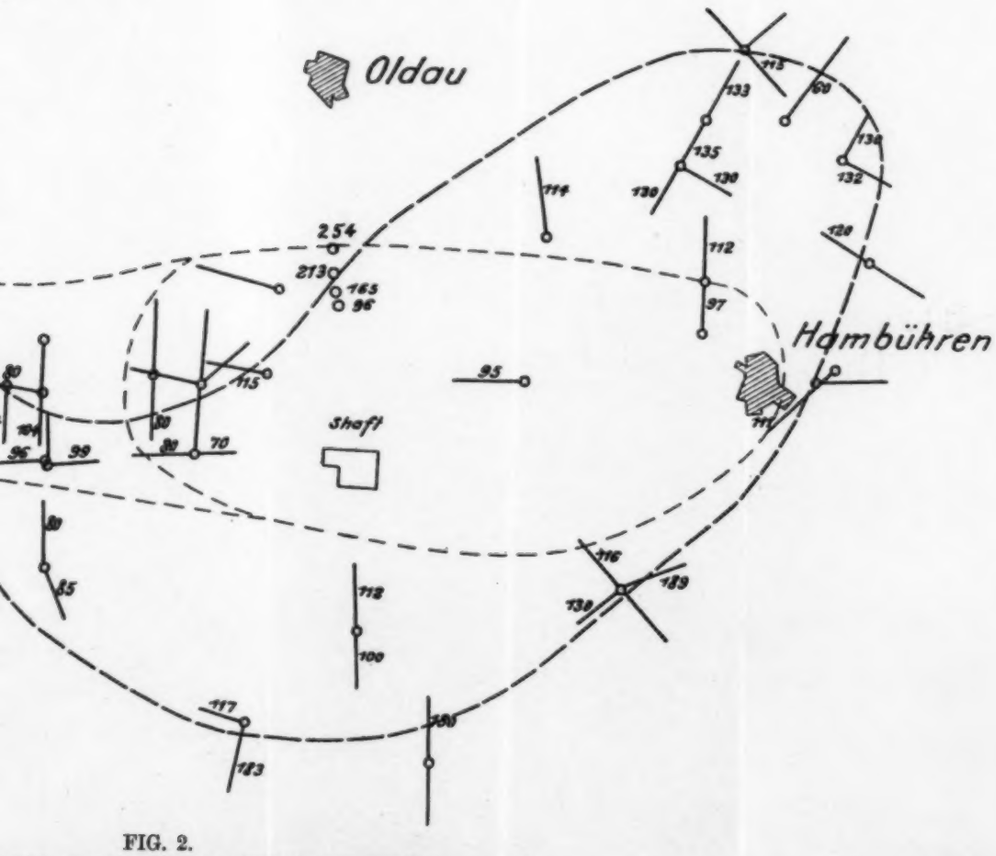

FIG. 2.

OME AREA WEST OF CELLE (GERMANY).

gations on the Salt Dome of Wietze-Steinförde-Hambühren.

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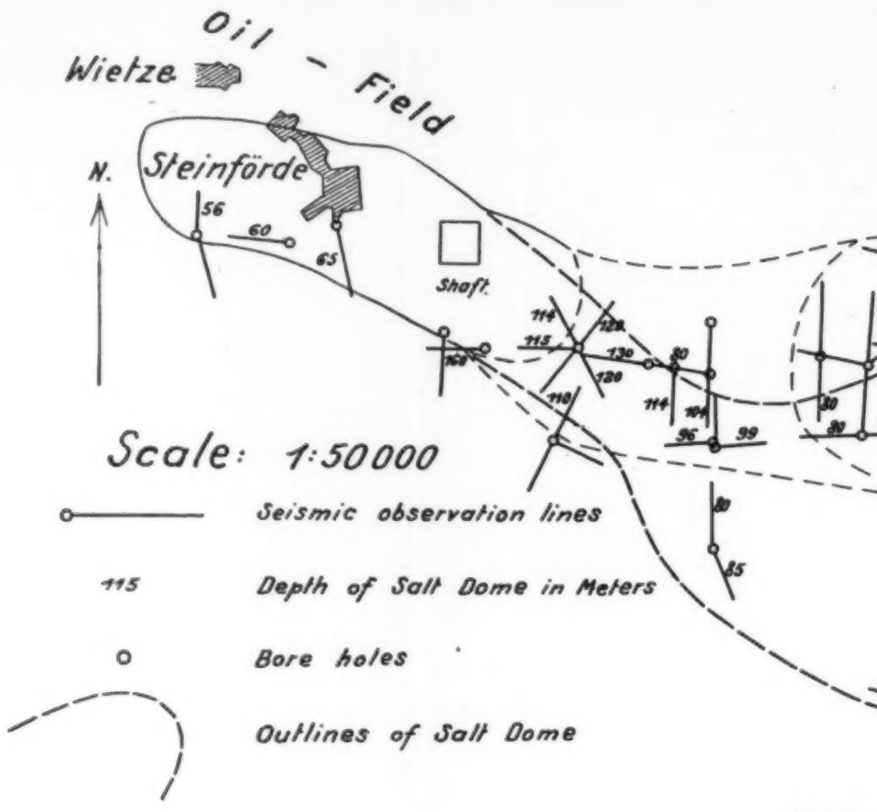

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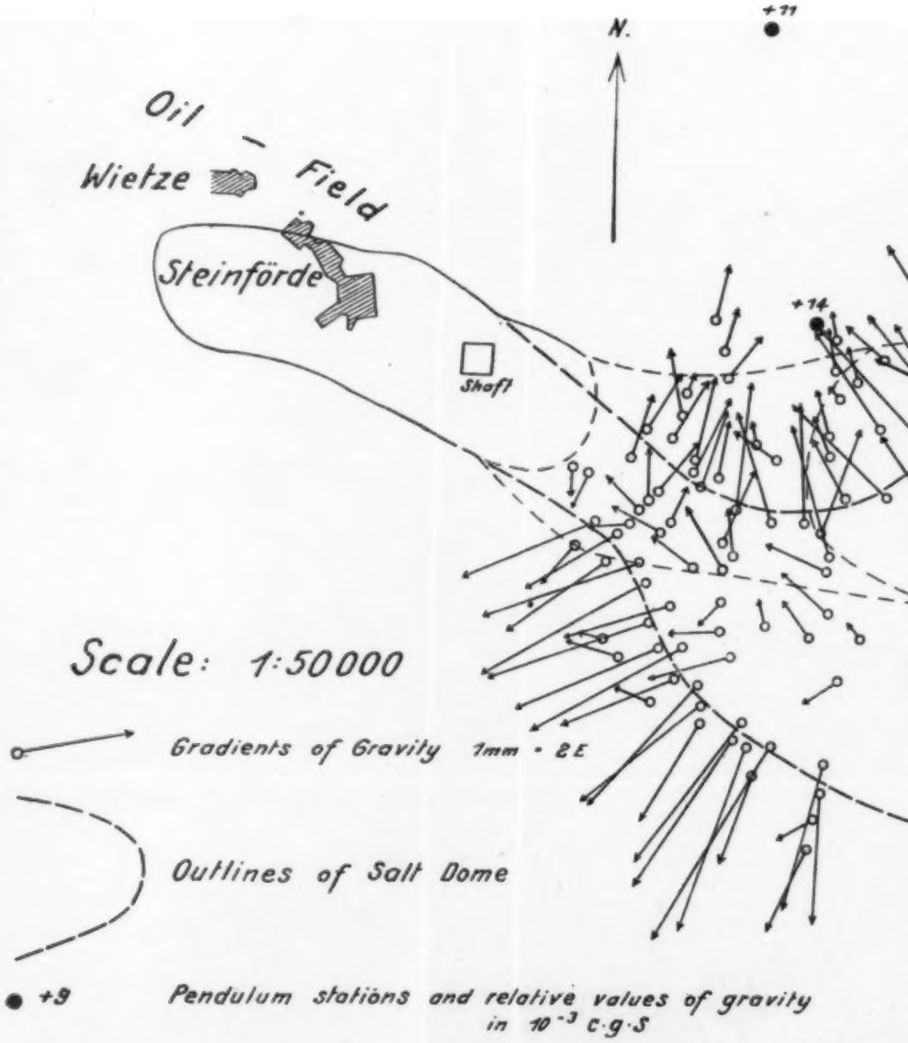
SCHMIDT: SALT DOME AREA WEST OF CELLE, GERMANY.



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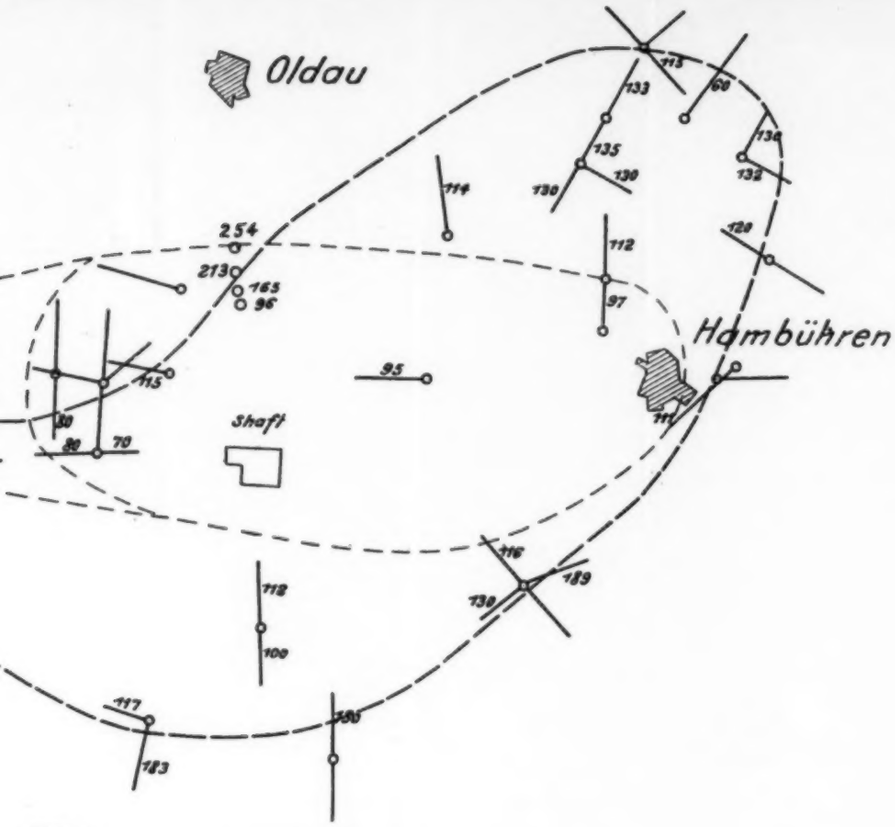

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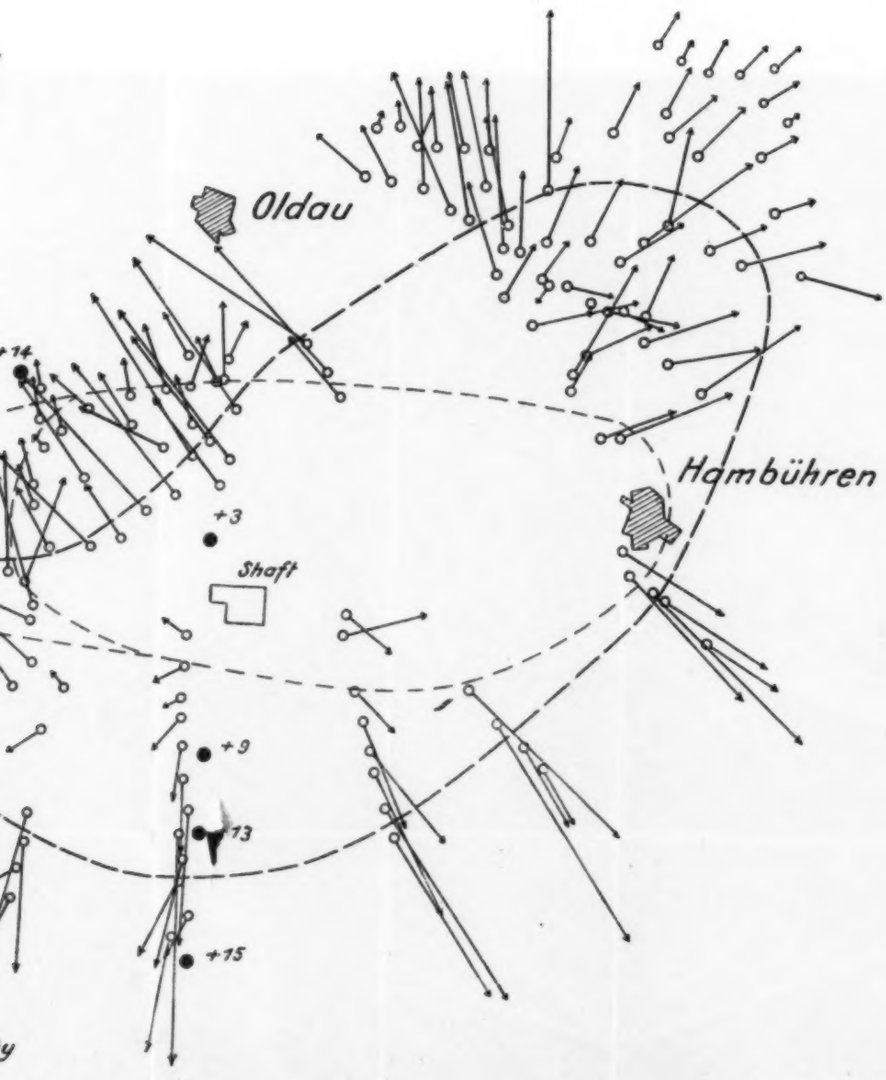

FIG. 3.
WEST OF CELLE (GERMANY).
the Salt Dome of Wietze-Steinförde-Hambühren.
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FIG. 4.

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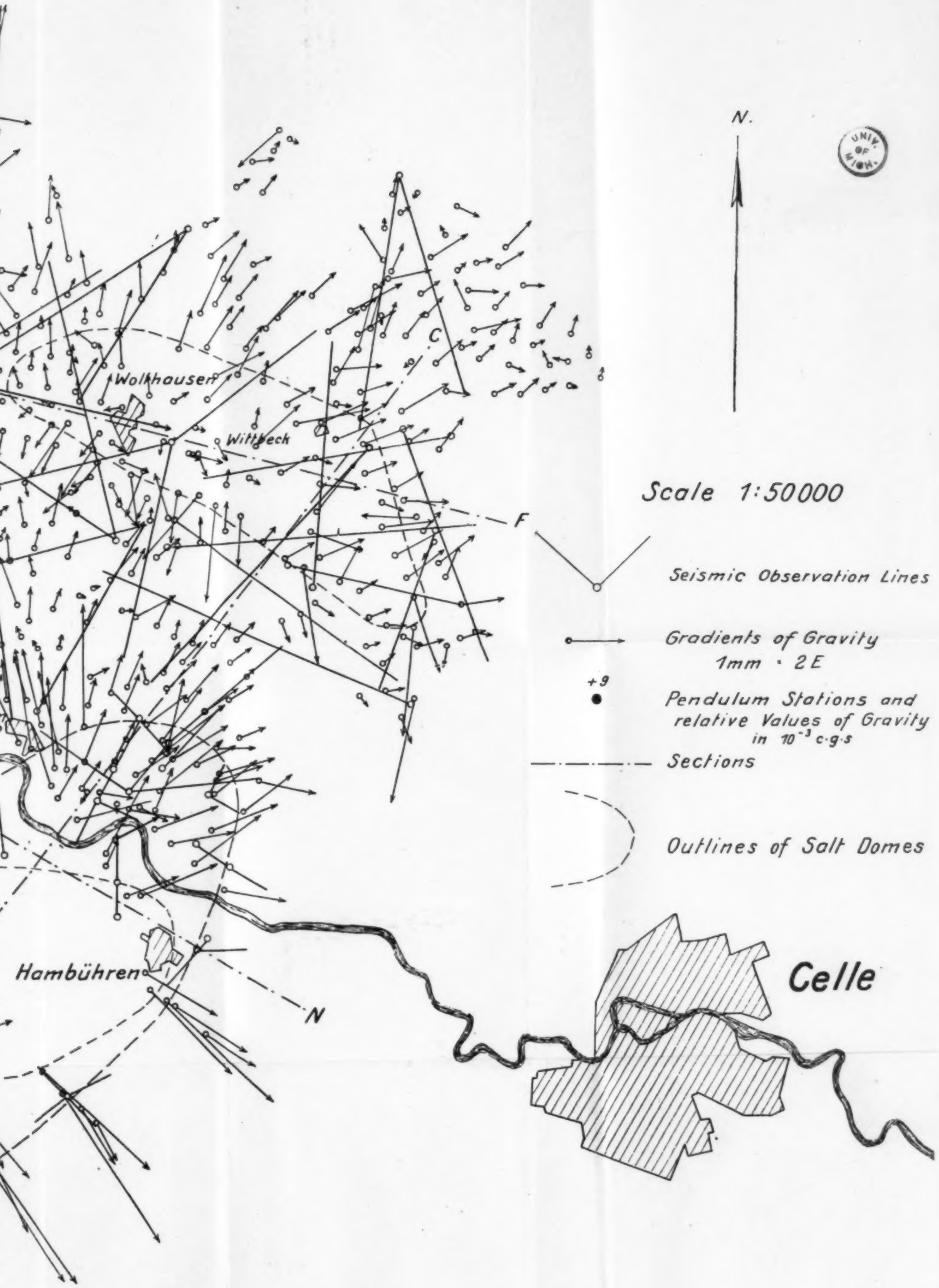

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FIG. 4.
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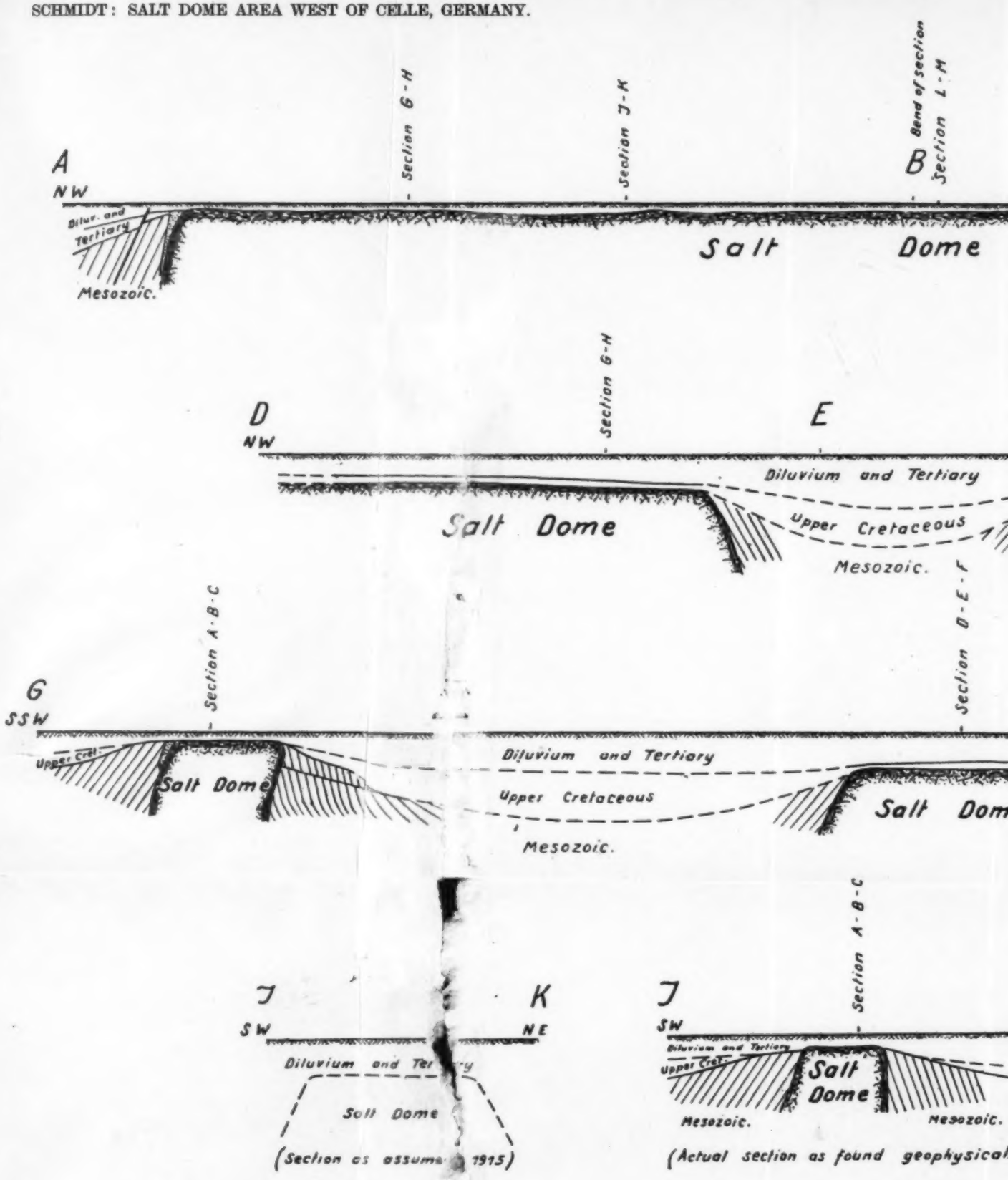

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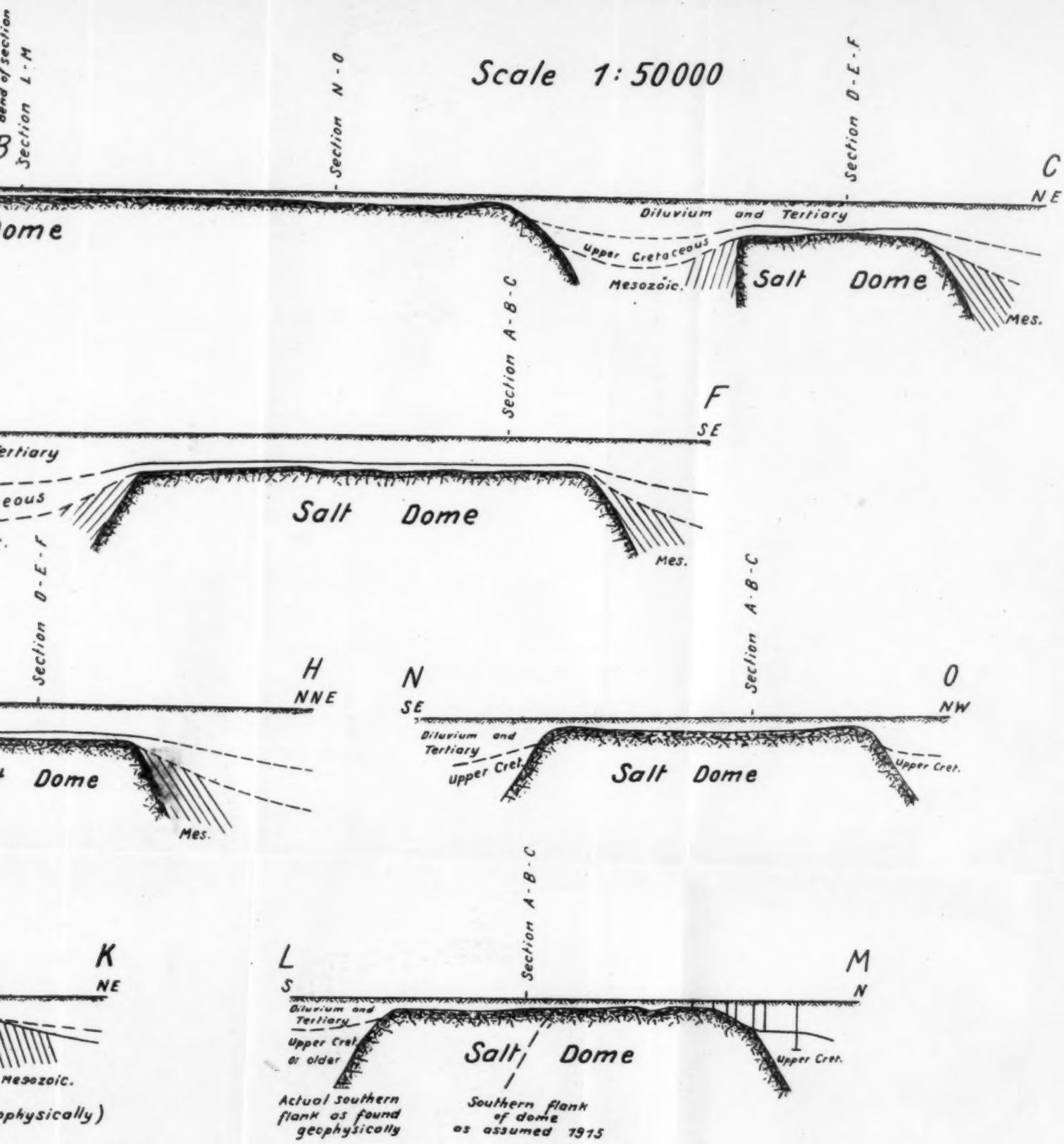

FIG. 5.

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type. There is little, if any, evidence of volcanic activity in either of the salt dome areas, but a great amount of it in at least five hundred of the seven hundred miles intervening between the two areas.

I see no evidence in the geologic histories of these three regions for Mr. Clapp's conclusion that the Tehuantepec salt dome region is "doubtless related genetically to the one in Texas and Louisiana." There are no known or suspected salt domes in the region of volcanic activity, and little or no evidence of igneous activity in the salt dome regions.

I reviewed this question some years ago[8] and concluded that "since the attractiveness of the theory of volcanic origin of salt domes lies in the similarity of structural effect produced by the intrusion of the salt in many domes to that produced by the intrusion of the igneous rock of a volcanic neck or plug, it follows that we are interested in the conditions and forces which caused the salt to act in a manner so like to that of an igneous magma." No condition was found in the salt dome region which required volcanic or igneous activity to explain it, nor has any additional evidence indicating igneous activity in connection with dome formation or growth been discovered in the dozen years since the paper was written. In fact, additional evidence supports the conclusion reached at that time.

I am in substantial agreement with the conclusions reached at the meeting of February 24th, 1931.

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[8] E. DeGolyer, Theory of Volcanic Origin of Salt Domes, *Trans. Amer. Inst. Min. Eng.*, 1919, 61. 456-69.

The Salt Dome Area West of Celle, Germany.

By Dr. Carl Schmidt.

The two lines of structural dislocation which seem to predominate in the tectonics of the underground of the North-German plain have a "Hercynian" (east-south-east–west-north-west) and a "Rhenish" (south-south-west–north-north-east) direction. One of the larger zones of dislocation in the Hercynian strike is the so-called "Aller Line," which extends from the area west of Magdeburg in the south-east to the area west of Bremen in the north-west, and along which the salt upthrusts of the so-called "Upper Aller Tal-Zone" and of Weyhausen, Wietze-Steinförde-Hambühren, Gilten, Rethem-Stöcken, Verden, Bremen-Hemelingen and some recent discoveries further to the north-west occur.

The salt dome of Wietze-Steinförde is of special note among these domes, as at its north-western corner, the oilfield of Wietze is situated where oil has been exploited since 1859 by numerous wells, and also for several years by mining operations. It was here at Wietze that the first oil well of the world was drilled in 1859, a little prior to the first oil well being drilled in the United States of America. Potash mines have also been worked on the Wietze dome as well as the Hambühren dome 4½ miles to the south-east. Prior to 1915, and notwithstanding that numerous bore-holes had been sunk, very little was known about the actual size and shape of these two domes, and the question whether such domes were separated from each other or whether there was a connection between them resulting in one large dome had not been determined. The geological map, 1 : 25,000 sheet "Winsen a.d. Aller," published in 1915, showed both possibilities, as illustrated by the dotted lines on Fig. 1.

In order to decide this question, seismographical investigations were carried out in 1922 by Dr. L. Mintrop (see Fig. 1). First the seismic observation-line No. I., on the Hambühren dome, was examined, with the result that the dome was encountered at a depth of 95 metres (313 ft.). The bore-hole nearest to line I. (a quarter of a mile to the south) had struck the dome at a depth of 87 metres (287 ft.), proving that the seismic data was in good accordance with the drilling result. Then the seismic observations lines II. and III., 2½ miles south-west of line I., within the possible gap between the two supposed domes, were examined. In such lines, the dome was encountered at depths of 99 metres (327 ft.) and

104 metres (343 ft.) respectively. By these seismic results, it was decided that there is only one dome, which extends from near Wietze to Hambühren, a distance of about 8 miles.

The next problem was to determine the actual size and shape of this large dome. This question has been solved by seismic investigations as well as by gravimetric investigations and the results of such work are shown on Figs. 2 and 3. Fig. 2 shows the seismic observation lines with the depths and the outlines of the dome as found seismographically. Fig. 3 shows the results of the torsion balance survey of the same area with the gradients of gravity and the outline of the dome derived from the interpretation of the torsion balance results. Curvature values corresponding in length and direction to the results indicated by the gradients were also calculated, but are omitted from Figs. 3 and 4 in order to leave a clear picture.

The outline of the two supposed domes, as shown by the geological map of 1915, is indicated on Figs. 1 to 4 by fine dotted lines, and it will be seen from such enclosures that the shape and area of the single dome, geophysically determined, is very different from the shape and area of the two domes anticipated prior to the geophysical investigations being carried out.

Pendulum observations were also made along a section running approximately north–south. The results are shown on Fig. 3, whereon the points of observation and the measured relative values of gravity have been inserted. On the big mass of salt which is lighter than the formations enclosing the dome, low values of gravity were obtained (+3 and +9), against higher values (+14 and +15) at points outside the dome.

The bending of the axis of the Hambühren dome from the west-north-west–east-south-east direction to a north-eastern direction appeared to be so interesting and important, that the seismic and gravimetric investigations were extended from the Hambühren area further to the north (see Fig. 4). As the result of this work a new salt upthrust was discovered in the area of Wittbeck-Wolthausen, having an average depth of 350 to 400 metres (1150 ft. to 1350 ft.). This dome, which is situated in the Rhenish direction relative to the Hambühren dome, has itself a pronounced Hercynian strike, but also shows a slight elongation in the Rhenish direction. The seismic data obtained in the area between the Hambühren dome and the Wittbeck-Wolthausen dome give indications that there may be at greater depths a narrow salt ridge or at least a dislocated zone forming some structural connection between the two great upthrusts. The formations above the Wittbeck-Wolthausen dome consist of Pleistocene, Tertiary and also Upper Cretaceous (Senonian), whereas the Wietze-Hambühren dome,

with its shallow depth of 50 to 100 metres (165 ft. to 330 ft.) is covered in some places by only Pleistocene and in others by Pleistocene and Tertiary.

After the discovery of the new dome of Wittbeck-Wolthausen, with its pronounced Hercynian strike, it was important to know the conditions in the area extending from Wolthausen towards the north-west and to connect the area so far investigated with the salt dome of Meissendorf. Further geophysical investigations were therefore carried out and the results are also shown on Fig. 4. It was found that the salt-dome of Meissendorf has an extension from the village of Meissendorf towards the south-east, and is in structural connection with the upthrust of Wittbeck-Wolthausen. The depth of this south-eastern part of the Meissendorf dome is about 350 metres (about 1150 ft. to 1200 ft.). The formations above this part of the Meissendorf dome consist of Pleistocene, Tertiary and Upper Cretaceous (Senonian). Seismic, as well as gravimetric data indicate the existence of structural dislocations, or even a narrow salt ridge, at a greater depth between the north-western edge of the Wittbeck-Wolthausen dome and the south-eastern edge of the Meissendorf dome.

With regard to the outlines of the Wittbeck-Wolthausen dome and the south-eastern part of the Meissendorf dome, shown on Fig. 4, it will be noted that the gradients are somewhat irregular in places. This feature is caused by the influence of the flank structures (indicated by the gravimetric as well as the seismic results), and therefore the outlines of the domes, as shown on Fig. 4, are at places mainly based on the seismic results.

A number of sections illustrating schematically the salt structures of the areas investigated geophysically are shown on Fig. 5. These schematical sections give a general picture of the conditions occurring along the flanks of the salt domes in north-west Germany.

Conclusion.

The seismic and gravimetric investigations carried out in the area of Wietze-Hambühren–Wittbeck-Wolthausen–Meissendorf revealed unexpected and very important geological conditions.

It was determined :—

1. That instead of there being two domes (Wietze and Hambühren) there is in fact only one large dome.

2. That the part of the dome around Hambühren is much larger than, and has an entirely different shape from, that anticipated. The axis of the dome having, in the north-western part, a Hercynian direction, bends to the Rhenish direction in the south-eastern part of the dome.

3. That in the direction of the Rhenish striking prolongation of the Hambühren dome there is another salt upthrust in the area of Wittbeck-Wolthausen, with a distinct Hercynian strike of its longer axis, and

4. That the dome of Meissendorf at its southern part has an elongation towards the south-east in the Hercynian direction.

The results of the geophysical investigations, *inter alia*, confirmed the importance of the two tectonic lines of dislocation of Hercynian and Rhenish strike in the underground structures of the North-German Plain, and showed that the occurrence of salt upthrusts is connected with such lines of tectonic dislocation and especially with the intersections of the predominant striking directions.

References.

[1] Geologische Spezialkarte 1 : 25,000. Bl. Winsen and Aller. Berlin, 1916.

[2] Erforschung von Gebirgsschichten und Nutzbaren Largerstatten nach dem seismischen Verfahren. *Mitteilungen der Seismos-Gesellschaft*, Heft 1, 1922.

[3] A. Kraiss, Geologische Untersuchungen über das Oelgebiet von Wietze in der lüneburger Heide. *Archiv für Lagerstättenforschung*, Berlin, 1916.

[4] G. Tuchel, Die Bedeutung der Drehwage für die Erforschung der Zechsteinsalzlagerstätten in der Norddeutschen Tiefebene. *Zeitschr. für Pumpen-und Brunnenbau, Bohrtechnik*, Berlin, 1924.

[5] A. Berroth, Referenzpendelmessungen am Salzhorst Oldau Hambühren (Hanover), *Zeitschrift fur Geophysik*, 1927.

Salt Dome Studies by Geo-Electrical Methods

By KARL SUNDBERG.

The geological structure of a region, consisting of sedimentary layers can be traced by geo-electrical methods, provided at least one of the layers possesses fair electrical conductivity and follows the general trend of the structure. Rock-salt is a non-conductor for electricity, and a salt-plug penetrating an electrically mapped bed may therefore be outlined as a hole in the conductor.

The Swedish electro-magnetic method for structural studies was developed about five years ago. This process consists in setting up a primary alternating magnetic field and observing at the surface the resultant field components or field vectors caused by the reaction of conducting sheets of different resistivity upon the primary field. The reaction is due to the fact that any alternating magnetic field induces secondary alternating currents in any conducting medium within its range, and that these secondary currents set up secondary alternating magnetic fields which in turn influence the primary field.

The problem to compute the influence of sub-surface conductors upon the resultant magnetic field at the surface has been solved completely and the theory and elaborate mathematical formulas, with the help of which these computations are carried out, have been checked by numerous laboratory experiments and extended field tests. The final solution of the problem characterises the different conducting layers in regard to their depth t below the surface and in regard to their so-called induction factor p. The value of the induction factor is dependent on the frequency of the alternating current and the effective thickness and specific resistance of the different layers.

Before considering examples from the field, two typical electrical indications across certain basic geological structures are given in Figs. 1 and 2. The following abbreviations are used : $p_0 - p_0$ induction factor of shallowest or surface conductor, $t_I - t_I$ and $p_I - p_I$ depth and induction factor of second shallowest or intermediate conductor, $t_{II} - t_{II}$ and $p_{II} - p_{II}$ depth and induction factor of deepest or sub-surface conductor. Fig. 1 represents the indications across a steeply dipping fault. The fault is reflected electrically as a jump in the depth lines of the two conductors, the induction factors remaining at constant value.

Fig. 2 represents the results of an electro-magnetic investigation across a salt-dome structure. The intermediate, as well as the sub-surface, conductor is pushed upward by the salt-plug. The

sub-surface conductor disappears with the salt. In many cases it is preferable to present the final result in the form of a contour map of the sub-surface conductor, the maps being easily constructed from the individual electro-magnetic cross-sections.

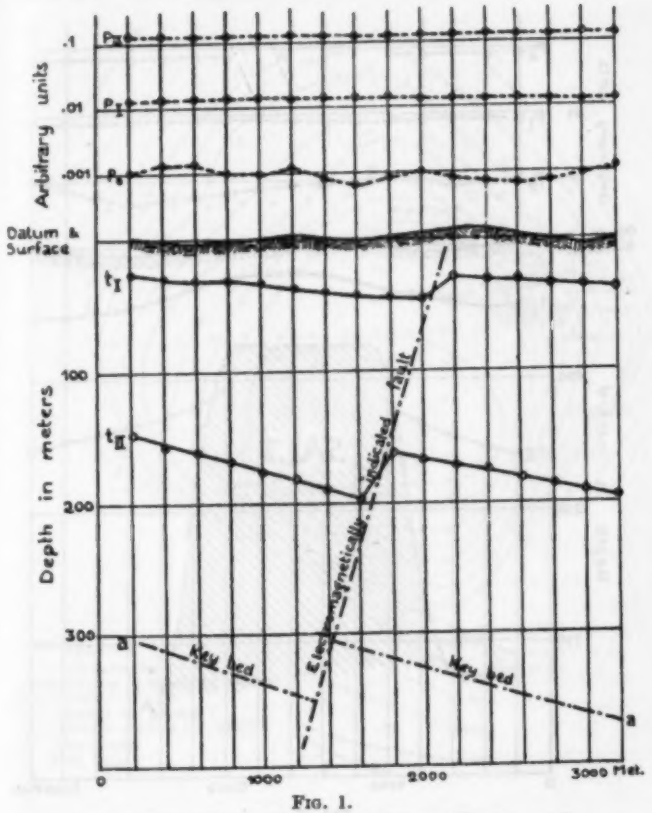

FIG. 1.

SCHEMATICAL ELECTRICAL FAULT INDICATION.

It is well known that during the last few years an astonishing number of salt domes have been discovered in the Gulf Coast region by geophysical, chiefly seismic, methods. Upon a salt dome being discovered it is important to obtain detailed information relating to its flanks and other features. Geo-electric methods have

proved successful in the determination of the flank conditions of salt domes and especially in locating faults against which oil may accumulate. The map of the Moore's Field dome (Fig. 3) shows how electro-magnetic methods give these details.

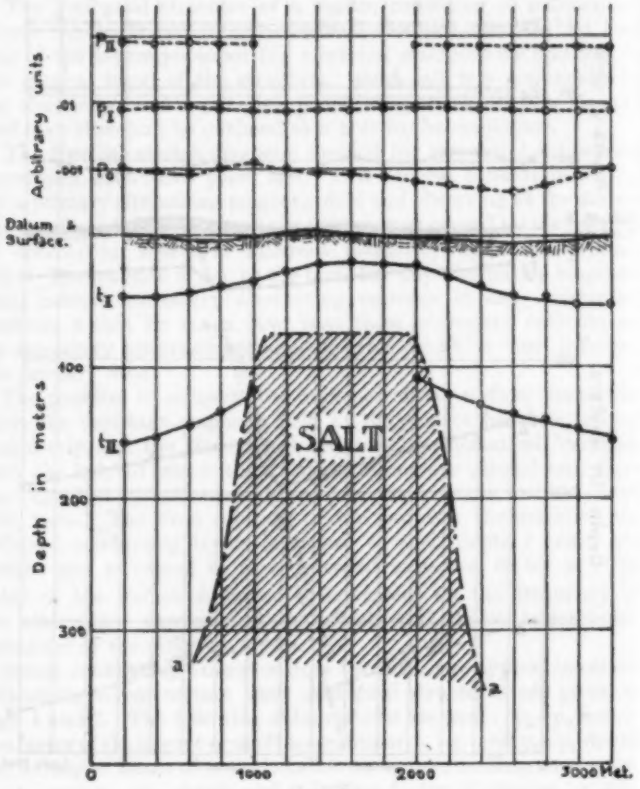

FIG. 2.

SCHEMATICAL ELECTRICAL SALT-DOME INDICATION.

A notable feature is the location of the fault C–D. The wells 18, 19, 20 and 21 were located outside the proper dome structure, close to this fault indication. Wells 18 and 20 are good producers, particularly the latter, which in March, 1930, came in with 2100 barrels a day, as by far the largest producer in this field. The

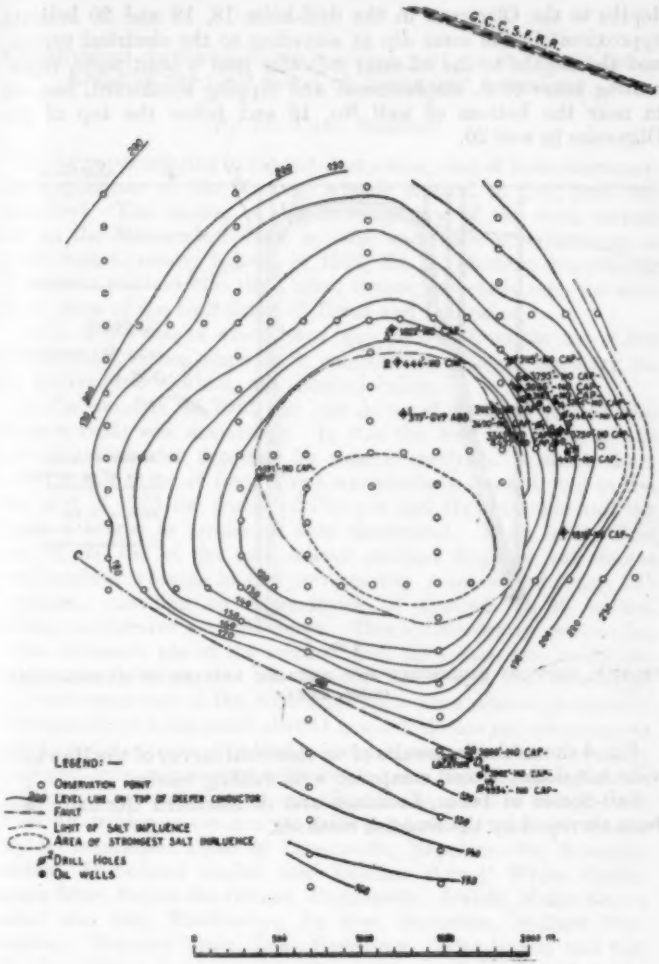

FIG. 3.

GEOELECTRICAL INVESTIGATION AT MOORE'S FIELD, FORT BEND COUNTY, TEXAS.

depths to the Oligocene in the drill-holes 18, 19 and 20 indicate approximately the same dip as according to the electrical survey, and the depths to the oil-sand indicates that a fault-plane, representing some 50 ft. displacement and dipping southward, has cut in near the bottom of well No. 18 and below the top of the Oligocene in well 20.

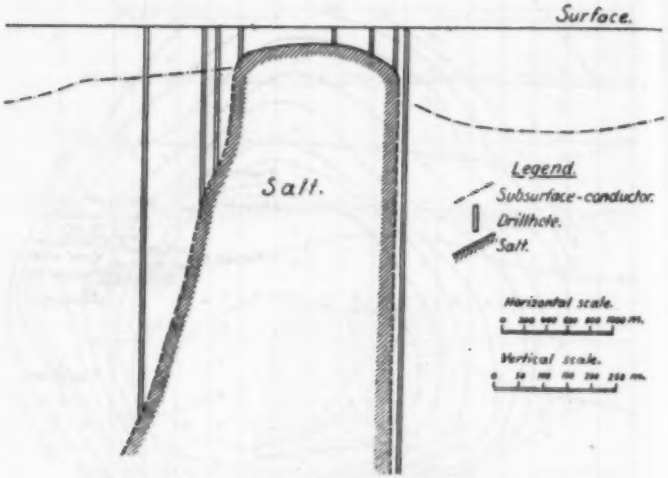

FIG. 4.

PROFILE, SHOWING ELECTRICAL AND DRILLING RESULTS AT HAWKINSVILLE DOME, TEXAS.

Fig. 4 shows similar results of an electrical survey of the Hawkinsville salt-dome, Texas, compared with drilling results.

Salt-domes in Texas, Louisiana and in Northern Germany have been surveyed by the Swedish methods.

Geophysical Investigations carried out in the Salt-dome Areas of the Gulf Coast of Texas and Louisiana.

By Dr. Carl Schmidt.

In the paper relating to the salt-dome area, west of Celle, Germany, the application of the Mintrop seismic method in that area was described. The success of this investigation, of the work carried out on the Meissendorf dome in 1920 and other investigations in north-west Germany led to, in 1923, Dr. L. Mintrop introducing his seismic method into the United States, especially into the salt-dome areas of the Gulf Coast of Texas and Louisiana.

Some of the results which have been derived from the use of the said method, either alone or in conjunction with, or ancillary to, the gravimetric method, are detailed below.

In the summer of 1924 the salt dome of Orchard (called also Moore's field) was discovered. It was the first salt dome in the Gulf Coast district detected by seismic methods. A short time, later the salt dome of Long Point was similarly located, and in the first part of 1925 the domes of Fannett and Hawkinsville and the dome of Starks in Louisiana were discovered. Thus, in the first year of the use of the said seismic method five new salt domes were located, whereas in the previous five years it had taken 735 boreholes, entailing an expenditure of upwards of 20 million dollars, to discover a single dome. This extraordinary success led to the extensive use of the method, and since then practically the whole area between the Rio Grande River and the Mississippi and vast areas east of the Mississippi have been seismo graphically investigated, with the result that 81 new salt domes and oil prospects have been discovered. Out of these seismic prospects 17 have already developed into commercial oilfields, 9 have had promising shows of oil and/or gas and the rest are either in the course of being tested for oil by drilling or are not yet drilled. Amongst such salt domes may be mentioned those of Loreauville, Napoleonville, Sorrento, Darrow, Thibodaux (called also Lutcher dome), White Castle, Bayou Blue, Bayou des Glaises, Haynesville, Arriola, Kelso Bayou (called also East Hackberry), La Rue, Hamshire, Mallard Bay, Danbury, Wormser Tract, Lake Hermitage, Cedar Bayou and Cut Off. In addition the method has been successfully employed in the said areas in detecting uplifts and folds in the Miocene.

Before the great campaign of geophysical methods in Texas and Louisiana, oil geologists were of opinion that salt-domes in the Gulf Coast of Texas and Louisiana would be found only at comparatively shallow depths. It is to the credit of geophysical methods

however, that they revealed the existence of salt-domes at much greater depths. The dome of Danbury, for example, found by the use of the said seismic method, is 5200 ft. deep. Other deep domes, for example, those of Sugarland, Mykawa, Citrus Grove, Shepherds Mott and Genoa were found gravimetrically.

Of all the geophysical discoveries mentioned above, those of Orchard and of Sugarland have had the greatest effect upon the history of exploration for oil in Texas and Louisiana. The discovery of the Orchard dome, together with the other discoveries in 1924–25 before referred to, proved the applicability and advantage of the use of the said seismic method in salt-dome areas and was largely responsible for the great and rapid development of the coastal plains of Texas and Louisiana. In the opinion of Mr. D. C. Barton, whose writings in relation to geophysical science are known throughout the world, the exploration of the coastal plains of Texas and Louisiana has, by the use of the seismic method, been advanced by about 75 years, as compared with a normal development by drilling only.

The discovery of the Sugarland dome proved the importance of deep-seated salt domes and its exploitation has furnished important data relating to the occurrence and oil potentialities of such deep-seated structures. In support of the value of these deep-seated salt domes it is interesting to note that about 69 boreholes have now been sunk on the Sugarland dome, of which 66 are producing oil, and one is a gas well, and also that in 1929 the production of oil from this dome was 3,900,000 barrels, and that in 1930 the production from this dome exceeded 4,000,000 barrels.

The extensive use since the summer of 1924 of the said seismic method, and of other geophysical methods of investigation, has resulted in the finding and exploitation of oilfields of enormous value and has enabled oil companies to avoid the expenditure of vast sums of money in fruitless drilling and to plan for many years ahead successful and economical drilling campaigns.

References.

1. D. C. Barton, "Geophysical Prospecting, 1929," American Institute of Mining and Metallurgical Engineers, New York, 1929.

2. D. C. Barton, Review of Geophysical Prospecting for Petroleum, *Bulletin of the American Association of Petroleum Geologists*, September, 1930, 14, No. 9.

3. D. C. Barton, "Applied Geophysical Methods in America," *Economic Geology*, 1927, p. 650.

4. Prof. Dr. Mintrop, Zur Geschichte des seismischen Verfahrens Zur Erforschung von Gebirgschichten und nutzbaren Lagerstatten, *Mitteilungen der Seismos-Gesellschaft*, Heft 2, 1930. Im Selbstverlag der Seismos G.m.b.H., Hannver.

5. *The Literary Digest*, Finding Oil with Earthquakes, April 25, 1925.

6. P. Wagner, "Seismographic System for Exploration of Underground Formation," *National Petroleum News*, April 11, 1923.

7. *The Oil Weekly of Houston, Texas*, Sept. 4, 1925, Finding Salt Domes that Formerly took Years of Drilling.

8. *The Oil Weekly of Houston, Texas*, Jan. 18, 1929, C. Malamphy, The Seismograph in the Gulf Coast.

9. *The Oil Weekly of Houston, Texas*, June 26, 1929, J. Logan, Discovery of Deep Domes Revises Gulf Coast Potentialities.

10. *The Oil Weekly of Houston, Texas*, Aug. 31, 1928, Gulf Coast Turns to Deep-seated Domes and Structures.

11. *The Oil Weekly of Houston, Texas*, Jan. 31, 1930, Geophysics Responsible for Fourteen New Fields in Gulf Coast.

12. *The Oil Weekly of Houston, Texas*, Nov. 16, 1928, Geophysics Reveal Vast Petroleum Deposits in Coast Region.

13. *The Oil Weekly of Houston, Texas*, Oct. 3, 1930, Map and Lists of Texas and Louisiana Salt Domes.

14. *The Oil Weekly of Houston, Texas*, 1924–30, article dealing with Geophysics.

15. *The Oil and Gas Journal*, 1924–30, Oklahoma, other articles dealing with Geophysics.

CURRENT PETROLEUM NOTES.

Motor Fuel Characteristics.—The 22nd Semi-Annual Motor Gasoline Survey of the U.S. Bureau of Mines deals with the tests made in 298 samples collected from service stations, and the results are given in Report of Investigations, No. 3063, by E. C. Lane, E. L. Garton and A. J. Kraemer. A further report, No. 3092, contains data on the anti-knock value of composite samples. Copies of both reports may be obtained from the Director, U.S. Bureau of Mines, Washington, D.C.

Carbon Black Production.—The production of carbon black in the U.S.A. amounted to 379,942,000 lb. in 1930, an increase of 3·7 per cent. over 1929.

Re-Forming Natural Gas.—Methods of re-forming natural gas and the results obtained by different systems are outlined in U.S. Bureau of Mines Technical Paper 483, by W. W. Odell. By this means city gas can be made at a low cost and a higher value given to natural gas. Waste still gases can also be economically converted into city gas. Copies of the paper are obtainable from the Superintendent of Documents, Government Printing Office, Washington, D.C., at 10 cents. each.

Canadian Petroleum Production.—The production of petroleum in Canada during January, 1931, amounted to 179,711 brls., compared with 100,496 brls. in January, 1930. Of this amount 168,785 brls. were produced in Alberta.

During the same period the production of natural gas amounted to 3,200,000 thousand cub. ft., of which 65·9 per cent. was produced in Alberta, 31·1 per cent. in Ontario, and 3 per cent. in New Brunswick.

CORRESPONDENCE.

To the Editor. April 20th, 1931.

Sir,—In a letter to me dated March 28th, from Khodoung, Upper Burma, Mr. W. E. V. Abraham, whose name I mentioned in my paper, "Gas in Relation to Oil Production" (pp. 2–29), writes as follows :—

"You were good enough to mention my name at the end of your paper. As this may be taken to imply general agreement with your arguments, I should be much obliged if you would ask the Editor to make it clear that my part in the paper was limited to the suggestion of the working rule, p. 17, as follows :—

'If a modification of producing conditions can be made so that a 50 per cent. reduction in gas production is accompanied by not more than a 10 per cent. reduction in oil production, it is worth carrying out.'

adding that this a general practical rule which has no detailed connection with any particular theory."

I regret that it did not occur to me that the mention of Mr. Abraham as having given helpful criticism might be taken to imply agreement with the matter in the paper. B. J. Ellis.

Britannic House,
Finsbury Circus,
London, E.C. 2.

REVIEW.

Entstehung, Veredlung und Verwertung der Kohle. By W. Petrascheck, H. Apfelbeck, H. Tropsch, R. Heinze, A. Czermak, F. Kothny, H. Löffler, A. Rozinek, J. C. Breinl. Berlin: Verlag von Gebrüder Bourtraeger. 1930. Pp. vi.+359.

This book consists of a series of lectures given to the Deutschen Technischen Hochschule in Prague and has been edited for publication by Prof. K. A. Redlich, Prof. J. C. Breinl and Priv.-Doz. H. Tropsch.

About half of the book is taken up by a monograph by Dr. R. Heinze on the drying and coking of brown coal. This deals with the physical and chemical properties of the brown coal, the present technical position of brown coal drying and coking, and the evaluation of the tar, coke, gas, and other products obtained from distillation. This article is fully illustrated with diagrams and photographs illustrating drying ovens and retorts for the treatment of brown coal.

Dr. H. Tropsch describes the synthesis of organic compounds from gases produced from coke, including also under this heading the production of methanol and higher alcohols from carbon monoxide and hydrogen mixtures.

The other articles deal with the relation between the properties of coal and its geological history, the composition and method of formation of coal, and special articles on the burning of solid fuels. F. H. Garner.